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Selection of management variables for regressing Iowa corn yields on management, climatic, and soil variables

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SELECTION OF MANAGEMENT VARIABLES FOR REGRESSING IOWA CORN YIELDS ON MANAGEMENT, CLIMATIC, AND SOIL VARIABLES

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Selection of management variables for regressing Iowa corn yields on management, climatic, and soil variables

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INTRODUCTION

Corn yield production is influenced by many variables within the broad categories of management, climatic, soil, and location variables. One way to formulate the relationship between yield and these variables is by the use of multiple regression with corn yield as the dependent variable and the management, climatic, soil, and location variables as the independent ones.

To study the relationships between corn yield and the many variables affecting yield for a large area such as Iowa, the range of observations for each variable should represent the range of values occurring in the population. A large number of observations throughout the state improves the possibility that the existing ranges of the variables in the population will be represented in the sample. Because climatic conditions are so variable, enough observations over years should also be obtained to sample adequately the climatic variations that occur.

A research project to collect data related to corn yields was conducted in Iowa from 1957 to 1970 in 15 counties representing all of the major soil association areas in Iowa except the Adair-Grundy-Haig soil association. Data were collected on corn yields and the many management, climatic, soil, and location variables influencing corn yields.

Several research studies have been conducted using these data to develop multiple regression models to explain the relationships between corn yields and the variables affecting them. The first study was conducted by Morris (1972) who derived the climatic indexes of soil moisture stress and excess moisture. He tested these indexes together with selected management and soil variables and found that they accounted for significant yield variation in the data from seven selected counties.

Henao (1976) continued the research, modified the climatic indexes, and selected the most important soil variables for regressing Iowa corn yields on soil, management, and climatic variables. He also observed that the presence of intercorrelations among variables in the multiple regression model caused difficulties in interpreting the regression statistics.

Pena-Olvera (1979) then studied and identified the intercorrelations occurring among variables. He also modified and tested the climatic indexes using data from seven western Iowa counties to select the most significant soil, climatic, and selected management variables in the corn yield regressions.

The remaining group of variables that needed to be studied in detail were the management variables along with the recomputed climatic indexes based on the research of Pena-Olvera (1979), using data from all 15 counties. Several of the management variables and a few soil variables were recoded or transformed to improve their usefulness in the regression analysis.

The objectives of this research were:

(1) To test and select the most significant management variables in the presence of the modified climatic variables in a series of quadratic multiple regression yield models;

(2) To test and select the most significant soil and location

variables in the presence of the previously-selected management and climatic variables in quadratic regression models;

(3) To test and select the most significant interactions between the variables and to select a final multiple regression quadratic model with linear by linear interactions for predicting Iowa corn yields; and

(4) To illustrate and interpret the relationships between corn yield and two or three interacting variables using the final yield prediction model.

LITERATURE REVIEW

Many research studies have investigated the effects of variables known to influence corn yield. These can be grouped into soil, climatic, and management variables; each of these broad groups contains a few to many variables. The magnitude of how each affects corn yield directly or indirectly, through its interrelationships with another variable or a few other variables, has been studied in many field experiments. By varying the level of one or more variables in the experimental treatments and by maintaining the other variables at uniform, optimum levels, the yield responses to the variable or variables being tested can be examined. Different experimental designs and statistical techniques are available to allow the investigator to study the effects of one or more variables carefully within the ranges of the other variables which can be controlled. Results of these investigations have been reported and reviewed by many researchers.

In field research, it is almost impossible to find experimental locations with different levels of many variables such as the soil and environmental variables known to affect yield. This has caused difficulties in using the results of an experiment from one location and year to predict yield responses at other locations and years having different soil and environmental conditions. For this reason, attempts have been made to develop experimental procedures to study the effects of many variables simultaneously on yield. The method used in this study was to measure corn yield and the many variables affecting corn yield over a wide range of management, soil, and climatic conditions. Yield then was related to these variables by the use of the multiple regression technique.

Previous studies of regressing Iowa corn yield on management, climatic, and soil variables will be reviewed primarily; these studies were by Morris (1972), Henao (1976), Pena-Olvera (1979), and Manu (1979) who used the same data as were used in this study. The major objective of this study was to examine the management variables in more detail than the previous investigators had done.

Management Variables

Most of the management variables measured or estimated were tested in the corn yield regressions in this study. They were divided into the environmental, tillage and planting, fertility management, and plow layer soil test groups for discussion. Extensive reviews of the effects of these related management variables have been presented by Pierre et al. (1966), Voss (1969), Benson (1974, 1976), Benson and Thompson (1974), and Aldrich et al. (1975).

Environmental variables

The environmental variables, most of which can be measured at harvest time, vary greatly from field to field and from year to year. Many can be controlled to a varying degree by pesticide and fertility management, but others are related to climatic variables which cannot be controlled except by management practices such as irrigation. The environmental variables discussed in this section include barren plants, root and stalk lodging, corn rootworm damage, and infestations of corn borers, weeds, and diseases. Although the climatic variables could be included in this section, they will be discussed later.

Barren plants   Barren plants or stalks may be related to low fertility, drouth, excessive plant density, insect damage to the roots, stalks, or emerging silks, poor timing of silking and pollen shed, and varietal differences (Aldrich et al., 1975). Lang et al. (1956) reported that barrenness was affected more by plant population than by hybrid or soil fertility.

In his regression analysis of Iowa corn yields on weather and management variables, Henao (1976) reported that deletion of the barren plants variable reduced the R^2 about 0.18 (18%) in both linear and quadratic models. He dropped this variable from his model because it is a yield component and is not a useful predictor of yields for the general population. Its presence also altered the effects of other variables on yield.

Pena-Olvera (1979) reported a high correlation between the barren plants variable and yield ($r = -0.46$) but it had no meaningful intercorrelation with the other management variables that he studied. This lack of intercorrelation may be because the highest amount of barrenness is related to two or more variables, including moisture stress. He also deleted barren plants from his final interaction model of corn yield on management variables.

Manu (1979) reported that deletion of the barren plants and silking date variables from his multiple linear regression of yield on selected variables markedly reduced the R^2 from 0.765 to 0.521. This effect agrees with those of Voss (1969), Morris (1972), and Henao (1976). Deletion of these two variables also increased the significance of several other variables. He explained that barren stalks and silking date variables, although highly related to yield, are poor predictors of yield in general regressions except for special cases.

Root lodging Root lodging is caused directly by high-velocity winds from early in the growing season until harvest. The weakening of the root system and subsequent root lodging was observed many years ago to be caused by fungous diseases (Pammel et al., 1915) and corn root aphids (Webster, 1917). In recent years, root lodging has most commonly been caused by corn rootworm infestation in late June and early July. However, root lodging frequently occurs in the absence of corn rootworm damage if wind velocity is high. The percentage of root-lodged plants in the field usually is related to yield loss; if the lodging occurs after physiological maturity, no yield loss occurs but harvest loss increases.

Henao (1976) found that the percentage of root lodging had a highly significant effect on yield in his prediction models. Yield was decreased linearly 0.5 bushels per acre per 10% increase in root lodging. In data from Western Iowa, Pena-Olvera (1979) failed to get a significant effect of root lodging on yield in his final regression on soil and management variables. Manu (1979) retained the root lodging variable although its regression coefficient was significant at only the 15% level.

Corn rootworm damage Three species of corn rootworm, the northern, western, and southern, are capable of causing severe corn yield reductions. The extent of economic losses by larval feeding on the roots depends on many factors, including number of larvae, size of the root system, availability of moisture and nutrients, root regenerative ability of the hybrid, and weather conditions (Stockdale and DeWitt, 1980). Root damage is slight in corn that follows any other weed-free crop. Rootworms find their most favored conditions when corn follows corn (Gunderson, 1963).

Turpin et al. (1972) regressed the corn root damage rating on soil, management, and weather factors. Their final regression equation included the following variates: slope, $slope^2$, drainage, $drainage^2$, percentage of clay, planting date, soil test K, soil test P, plant density, slope*drainage, and slope*percentage clay. The model explained 35% of the variation in the root damage rating ($R^2 = 0.35$) with the F-ratio significant at the 1% level. Based on the Iowa State scale for rating rootworm damage, they showed that corn yield had little relationship with damage ratings below 2.5. Damage ratings greater than 2.5 were linearly related to decreasing yield; a damage rating increase of 1.0 from 2.5 to 5.5 was associated with a 10 bu/acre (6.3 q/ha) yield reduction.

Henao (1976) found that the root damage rating had a significant negative effect on corn yield primarily through a highly significant interaction with soil test P of the plow layer. Pena-Olvera (1979) reported a highly significant, negative, linear effect of root damage rating on yield modified by significant interactions with years (trend), slope of the site, and organic carbon content of the plow layer. Significant interactions between corn root damage rating and date of planting, P fertilizer application, and moisture stress index were reported by Manu (1979).

Stalk lodging Stalk lodging (breakage below the ear node) may reduce yield and cause harvesting losses. It may be caused by corn borer, corn stalk rots, 2,4-D damage, or genetic differences in the hybrids. Corn stalk rots are present to some extent in every Iowa cornfield at harvest time; severity varies from year to year. Stalk rot is caused by several different fungi and bacteria. Fungi are the most common cause of stalk rots in Iowa (Nyvall, 1976). Tillage systems, N and K fertility levels, and hybrid characteristics influence the degree of disease infestation (root and stalk rots) in the corn plant (Parker and Burrows, 1959). They usually cause the greatest economic loss of any corn disease in Iowa (Benson, 1976). Aldrich et al. (1975) reported that an increased K level reduced lodging because it reduced stalk rot but an increased N level increased lodging and stalk rot.

Only Manu (1979) included the percentage of stalks broken below the ear node as a variable in his yield regression models. The stalk lodging variable had a linear, negative coefficient significant at the 5% to 10% level in his final models. No interaction variate involving this variable was selected but only two were tested.

Corn borer infestations Corn borer attacks all parts of the corn plant. There are usually two generations of European corn borer a year in the Corn Belt. Entomologists estimate that yield is reduced 3 to 4 percent for each first generation borer that matures in a corn plant and about 2 percent for each second generation borer (Aldrich et al., 1975).

The first generation borer causes stunted plants and broken stalks below the ear node, whereas the second causes dropped or shrunken ears and broken stalks generally above the ear node.

The fastest growing corn attracts more moths and more eggs are laid in these fields. Scott et al. (1965) reported that N fertilization increased the first-brood corn borer rate of oviposition, larval survival per plant, stalk lodging, and yield loss. Everett et al. (1959) reported that first brood ovipositing moths consistently preferred early planted corn to late planted corn during four years of experiments conducted in Iowa, Minnesota, and Ohio. The second-brood moths, however, preferred the late planted to early planted corn.

Henao (1976) in data from all of the state and Pena-Olvera (1979) and Manu (1979) in data from western Iowa found highly significant, curvilinear effects of both first- and second-brood corn borer infestations on corn yield in their quadratic models. Significant curvilinear effects of both corn borer variables occurred in the final interaction models reported by Henao, only a curvilinear effect of second-brood borer on yield occurred in those of Pena-Olvera, and only a curvilinear effect of first-brood borer on yield occurred in those of Manu.

Significant interactions were reported between first-brood corn borer and plant density, second-brood corn borer, and moisture stress (Henao, 1976), pH of the plow layer, soil test N, township location, and plant available water capacity (Pena-Olvera, 1979), and planting date and erosion class (Manu, 1979). Significant interactions between second-brood corn borer and plant density and silking date were also reported by Pena-Olvera. All three investigators found that maximum corn yields occurred at moderate first-brood and moderate-severe second-brood corn borer infestations instead of at very low levels as was expected. Henao (1976) indicated that the best corn attracted more egg-laying corn borer moths and that the confounded effects of high potential yields and high corn borer infestations were not separated by the multiple regression models.

Weeds Weeds compete for water and light as well as for nutrients. Their effect on corn growth may be severe during the early season. Allowing weeds to grow for only 2 weeks after the corn emerged caused a yield loss of 6.3 q/ha (10 bu/acre), and for 3 and 5 weeks caused further yield losses (Aldrich et al., 1975). Weed control is usually more difficult in reduced than in conventional tillage. The important weed species found in corn vary considerably in morphology, taxonomic classification, and growth habit. Both broadleaf and grassy types are serious weeds.

Henao (1976) found that total broadleaf and grassy weeds had a highly significant, negative effect on yield in his multiple regression models. None of the few interactions tested between weeds and other variables had a significant effect on yield. Pena-Olvera (1979) also found a significant, negative, linear effect of total weeds on yield; this effect was modified by significant interactions with township location and moisture stress index. Manu (1979) found similar effects of weeds on corn yield as Pena-Olvera had except that the interaction between weeds and township location was not significant.

Corn diseases   Several corn diseases infesting the leaf and other above-ground parts now have been controlled by corn breeding (Nyvall et al., 1978). The root and stalk rots were discussed previously in the stalk lodging section. Because hybrid varieties now grown are resistant to leaf diseases encountered during this study, the disease variable was eliminated by adjusting corn yield to a disease-free basis.

Tillage and planting variables

Soil tillage affects corn yield through its influence on seed germination and root environment. It has a major influence on water intake, storage, and evaporation, and on the extraction of water from the soil by plant roots (Larson, 1967). Tillage sometimes creates improved physical conditions that result in better air-water-temperature relationships and reduced root impedance (Larson and Blake, 1966). Tillage variables discussed in this section include the time of plowing and number of tillage operations after plowing and after planting. Planting date, planting method, and plant density are important variables which, through their interactions with other management, climatic, and soil variables, modify growth performance and yield. Silking date is included in this discussion because it is highly correlated with planting date (Henao, 1976), but it is also affected by hybrid variety, fertility, and climatic variables.

Plowing and other tillage operations   Conventional tillage has included plowing in the fall or spring followed by a number of tillage operations before planting. Larson and Blake (1966) explained that the effect of spring versus fall plowing depends on a number of conditions. Special problems, such as weed control, erosion hazard (either by wind or water), or water conservation or disposal, may be the dominant considerations in time of plowing, depending on local climates, topography, and soil type. Long term research comparisons show little difference in corn yield between fall or spring plowing (Aldrich et al., 1975). Fall plowing will allow earlier planting than spring plowing, particularly on the more poorly drained soils.

More recently, tillage methods that eliminate moldboard plowing have become much more popular in the corn belt (Griffith et al., 1973). For soil conservation purposes, no-tillage or reduced tillage systems have received more and more attention. Availability of herbicides for weed control contributed to the increasing use of no-tillage systems. Olson and Shoeberl (1970) compared conventional tillage and three reduced-tillage systems on corn yield. They concluded that reduced-tillage systems with their lower cost and greater protection from water runoff and erosion can be used in the western Corn Belt with little or no yield loss. These results agree with those reported by Fink and Wesley (1974) in Illinois.

Amemiya (1968) reported that crop responses to tillage methods in the Corn Belt frequently varied among years and locations. Corn experiments conducted in Iowa during 1956-66 indicated that the effectiveness of tillage methods was associated with weather and consequent soil water conditions. On Moody silt loam in northwestern Iowa, severe soil water deficits occurred in 6 of the 11 years. In these years, lister-planted corn outyielded conventionally-planted (plow-disk-harrow) corn by as much as 26 q/ha. These responses were related to differences in plant available water attributed to tillage. Under favorable weather and soil conditions, little yield difference occurred among tillage treatments.

Henao (1976) and Pena-Olvera (1979) did not include any of the tillage variables in their studies. Manu (1979) included several variables involving time of plowing and total number of times that the corn was tilled after plowing and before planting and number of times the corn was harrowed, rotary hoed, and cultivated after planting. None of these variables, however, had a significant effect on yield in the mostly well-drained, upland soils used in his study.

Planting date Benson and Thompson (1974) reviewed extensively the planting date research. Most experiments have shown higher yields from early than late planted corn. Long term studies indicated that, on the average, yield declined if planted after May 10 to 15, but the exact date varied from year to year. About 50 percent of Iowa's corn is normally planted by that time. Little difference in yield occurred from planting dates ranging from April 16 to May 12. Over a period of years, April 20 to May 10 was the best time to plant corn in much of Iowa. Some other effects of planting date on corn growth were as follows: (1) population-intolerant hybrids became more population tolerant if planted early; (2) with delayed planting, the length of time from tasseling to silking became longer, which caused more barren plants, even with irrigation; (3) late planting, especially with higher populations, caused more small, spindly plants dispersed among normal ones; and (4) mid- to late-May plantings produced taller plants, greater ear height, and more lodging than earlier or later planting dates.

Both Henao (1976) and Pena-Olvera (1979) found a curvilinear effect of planting date on yield in their final regression models. Maximum yield occurred at a planting date of May 2 to 14 in Henao's final models. The planting date that gave maximum yield in Pena-Olvera's models was dependent on interactions between planting date and silking date and, particularly, the moisture stress index. Planting date for maximum yield varied from May 16 to May 6 as moisture stress varied from moderate to none.

Planting method   Three methods of planting were used in previous years. The wire-checked method placed a given number of seeds at the corners of a square; the hill-dropped method placed 2 to 4 seeds in hills at a certain interval along the row; and the drilling method placed single seeds at regular intervals along the row. The drilling method is used in most fields now. Colville and McGill (1962) reviewed the results on planting methods. Their experiments and others showed that yields of drilled corn were superior to those of both the hill-dropped and wire-checked methods. In another experiment, Colville (1968) reported that light was the only factor influenced significantly by planting patterns.

Plant density   Plant density along with N fertilization and soil moisture stress are the most important variables affecting corn yield. Rossman and Cook (1966) explained that for a given hybrid, yields of corn generally increased as population increased until other factors (available plant nutrients, water supply, soil fertility, soil organic matter content, cultural practices, climate, or light) became limiting. In most reports, soil fertility and moisture appeared to be among the first variables to limit response to increasing plant density. In addition to yield, rates of planting were observed to affect several plant characteristics, such as size of ear, number of ears or barrenness, lodging, tillers, protein and oil content, corn borer infestation, stalk rot, plant and ear height, and leaf area. Some of the effects were small or negligible while others were of considerable importance.

Bondavalli et al. (1970) regressed corn yield on plant density, N fertilization, climatic variables of rainfall and temperature in different growth stages, and location in the state using a curvilinear regression model with interactions. The data came from three experimental farms in Missouri. Their model with 28 variates explained 70% of the yield variation; both the temperature and rainfall variables affected yield significantly. The economic optimum plant density and rate of N fertilizer at the mean rainfall for the growing season were 41,850 plants/ha (16,950 plants/acre) and 163 kg N/ha (145 lb N/acre). The optimal input of nitrogen was relatively sensitive to the rainfall level but the optimal plant density was less affected.

Holt and Timmons (1968) regressed corn yield on available soil water, plant density, precipitation received for three weeks after the 30-cm high stage, and precipitation received from the third through sixth week (kernel formation) after the 30-cm high stage. For 17 locations in western Minnesota and eastern South Dakota, they reported that the multiple regression accounted for 91% of the variation in corn yields during the four-year period. Yield response to plant density was markedly affected by available water and precipitation.

Most profitable corn plant density for Iowa conditions usually ranges from about 40,000 to 60,000 plants per ha (16,000 to 24,000 plants per acre). The ideal plant population is not constant, but depends on factors such as hybrid, moisture level, fertility, and yield goal. The recommended harvest population for various parts of Iowa was given by Benson (1974).

Henao (1976) found that plant density had a highly significant curvilinear effect on yield with maximum yield occurring at 64,000 plants/ha (26,000 plants/acre) in his quadratic model. In the western Iowa counties, Pena-Olvera (1979) and Manu (1979) also found highly significant curvilinear effects of plant density on yield, but maximum yields occurred at plant densities of 44,000 to 47,000 plants/ha (18,000 to 19,000 plants/acre) in their quadratic models. All three researchers found highly significant interactions between plant density and moisture stress on yield. Pena-Olvera (1979) showed that plant density as maximum yield varied from 29,000 to 52,000 plants/ha as moisture stress varied from severe to none. Other interactions involved plant density and both broods of corn borer, N and P applications, and erosion control variables.

<u>Row spacing and direction</u> An increasing percentage of Iowa corn is planted in 76 cm (30 inch) rows (Benson, 1976). He reported that research in the Midwest has shown that yields averaged 4 to 6 percent

higher in 76 cm than in 100 cm rows. Responses have varied depending on moisture stress and potential yield level.

Rossman and Cook (1966) and Yao and Shaw (1964) reported no difference in corn yield between corn planted in east-west and north-south directions. Net radiation at the soil surface averaged 3 percent less for north-south than for east-west rows and from July 15 to August 15 it was about 10 percent less. Pendleton et al. (1963) found no significant effect of row direction on yield of either corn or soybeans in either an alternating-row pattern or in a solid-row planting. Manu (1979) included row width and row direction variables in his initial regression models but neither one had a significant effect on corn yield.

Silking date   The silking date, date when 50 or 75% of the plants show silk emergence, is an important phenological date in the morphology or development of corn. It is a key date in the determination of the Dale and Shaw (1965a) moisture stress index.

Henao (1976) reported that yield and silking date were highly correlated ($r = -0.46$) and that silking date also was correlated with years or trend ($r = -0.27$), plant density ($r = -0.25$), first-brood corn borer infestation ($r = -0.35$) and planting date ($r = -.64$). Henao also regressed silking date on quadratic functions of all other environmental and management variables except barren plants ($R^2 = 0.55$). Variables that had significant effects on silking date included trend (years), plant density, first- and second-brood corn borer, planting date, total N applied, cropping sequence (rotation), excess moisture index, moisture stress index, and plow layer soil tests of pH, N, P, and K. Henao deleted silking date from his final regression models because it, like barren plants, was a component of yield, its many intercorrelations with other variables interfered with determination of their effects, and it is a poor predictor of yields in most cases unless silking dates are determined.

Casanova (1979) found high correlations of 0.45 to 0.91 between planting date and silking date in the long-term rock phosphate-superphosphate experiments at four experimental farms. He also found significant correlations between silking date and yield, moisture stress, early season precipitation, mid-season to late season precipitation, heat unit indexes, and soil pH at one or more of the experimental locations.

Pena-Olvera (1979) included the highly significant silking date variable in all of his yield regressions. In the intercorrelation analysis, silking date was involved in interdependencies with planting date, plant density, trend (years), corn rootworm, both corn borers, weeds, tile distance, crop rotation, all soil tests, and N and P fertilizers. In his final regression model, silking date had a curvilinear effect on corn yield modified by significant interactions with first-brood corn borer, planting date, soil pH of plow layer, and moisture stress.

Row slope and slope ratio The slope of the corn rows through an area gives the degree that the corn was planted on the contour. Rows with a zero slope are planted on the contour; the maximum slope of rows planted up-and-down hill is equal to the slope of the site area. Row slope alone has little utility; its relationship to the site slope gives the degree that the area was planted on the contour. For this purpose, the ratio of the row slope to the site slope can be used as a variable. If the rows are on the contour, the ratio will be 0, but if up-and-down hill, the ratio will be 1.0. Since a ratio of 1.0 (up-and-down hill) has a different effect on erosion and yield if the site slope is 2% as compared to 20%, the row slope and slope ratio variables should be interacted with the site slope to obtain the expected differential effect of either one over a range of site slopes.

Manu (1979) included slope ratio as a variable in his yield regressions. In the quadratic model, minimum yield occurred at a coded slope ratio of 59 (multiplied by 100 to eliminate the decimal point); a value closer to 100 was expected, however. In the interaction models, he tested interactions between slope ratio and site slope, erosion class, years contour planted, and years terraced. The slope ratio variable and its interactions were deleted, however, from the final regression models because of nonsignificance.

Erosion control variables Manu (1979) extensively reviewed the effects of erosion control variables on corn yield. In his study of the effects of years of erosion control practices on yield, using data from upland soils from five southwestern and western Iowa counties, he included years contour plowed, years contour planted, and years terraced in the multiple regression models. Years contour planted and years terraced had highly significant curvilinear effects on yield in his final models modified by significant interactions with plant density, crop sequence (rotation), site slope, and erosion class.

For this study, the erosion control variables were not included because most of the contoured and terraced sites occurred in the five counties included in the research by Manu (1979). Several of the other counties had no sites contour planted and several others had no terraced sites.

Fertility management variables

High corn yields depend on the availability of nutrients and favorable environmental conditions. The availability of soil nutrients is affected by soil physical and chemical characteristics. Correction of soil pH by liming commonly increases crop growth through increased availability of nutrients. Crop residues, manure, and fertilizer provide additional plant nutrients to supplement the available soil nutrients.

The major nutrients needed by corn in ample amounts are N, P, and K. Yield responses to fertilizer applications depend on many factors. For efficient fertilizer use, various rates, methods, and times of application have been investigated. Most agronomic research has been on fertility management, particularly, fertilization. Extensive reviews of N, P, and K fertility management are in Pierre et al. (1966), Desselle (1967), Voss (1969), and Casanova (1979). This review will cover primarily the research on the effect of fertility management in multivariable regression models.

Liming Soil acidity influences plant growth in many respects; availability of nutrients for plants depends on soil pH (Thompson and

Troeh, 1978; Tisdale and Nelson, 1975; Black, 1968). Optimum pH for plant growth is reported to be between 6.5 and 6.8. Liming is likely to become more important with the increased use of acid-forming N fertilizers in intensive corn culture. The optimum pH for corn in Iowa is about 6.5 (Voss et al., 1965).

Iowa soils differ greatly in lime needs. The degree of acidity of the surface soil varies among and within soil types because of naturally occurring processes and past management practices (Voss et al., 1965). They listed the benefits of liming as follows: it reduces soil acidity, increases availability of P and certain micronutrients, produces a more favorable soil environment for bacteria and other microorganism which speeds the decay of organic matter and release of N and P, increases the inoculation of legumes with N-fixing bacteria, improves calcium supply which is essential for plant growth, and reduces activity of elements such as aluminum and manganese which are toxic to plants. Further discussions on the effects of liming and/or pH changes on the availability of individual nutrients and corn yield responses have been given by Claassen (1971).

The lime variable was included in this study although the effects of liming may be accounted for by the pH of the plow layer.

Manuring Barnyard manure has been extensively used as a source of nutrients for crops. The commonly used figures for nutrients in 9 q (1 ton) of fresh cattle manure with a moderate amount of bedding are 4.5 kg (10 lb) of N, 2.3 kg (5 lb) of P_2O_5, and 4.5 kg (10 lb) of K_2O (Aldrich et al., 1975). About half of the N will become available in the year of application.

Many experiments have been conducted with manure rates as a variable, particularly in rotation experiments in which manure and N fertilizer rates were compared. Barnyard manure is also an effective source of K for corn (Dumenil et al., 1959); an application of 11 to 22 metric tons/ha (5 to 10 tons/acre) of manure should supply adequate K for corn on most Iowa soils.

Henao (1976) did not include the manure variable in his yield regressions. Manu (1979) included it in his preliminary regression models in which it had a significant effect on yield. Later, he used nutrient variables of total N, P, and K from manure and fertilizers to reduce the number of interactions to be tested.

Pena-Olvera (1979) reported that corn yield was increased only 0.3 bu/acre per ton of manure on the average. Estimation of manure effects in western Iowa was poor because few sites had been manured, particularly in the later years of the study.

Fertilization During the period of this study, the percentage of fields fertilized and fertilizer rates increased markedly. N fertilizers from various sources (ammonia, N solutions, ammonium nitrate, urea and ammonium phosphate) were applied pre-plant, either in the fall or spring, and side-dressed after planting. Most was applied as a straight N source, either injected into the soil or broadcast; the rest was mixed with P and K materials and broadcast prior to plowing or after plowing. The source of broadcast P fertilizer was superphosphate and ammonium phosphate and the source of K fertilizer was KCl. These P and

K fertilizers were broadcast and plowed under or disked in after plowing. Row fertilizers, usually containing N, P, and K, were applied with a planter attachment at planting time at most sites in eastern Iowa but at relatively few sites in western Iowa. Nutrients were usually applied at lower rates by row fertilization than by other methods.

Many experiments have been conducted in the last 30 to 40 years in the United States relating corn yield responses to rates of N, P, and K, the major nutrients. The earlier research results have been reviewed extensively by Viets (1962), Voss (1962), Pierre et al. (1966), Desselle (1967), and Voss (1969). Relationships between corn yield response and N, P, and K fertilizers were related to soil, climate, and management practices.

Heady et al. (1955) were among the first to use regression analysis to relate corn yield responses to fertilizer rates so that economic analyses could be made. They concluded that quadratic functions plus interaction terms could adequately describe corn yield response functions to nutrient rates in multi-variable fertilizer experiments. Most research studies on fertilizer rates and other variables in Iowa have followed their principles and multiple regression methods.

Voss and Pesek (1967) conducted NPK rate experiments on the Clarion, Nicollet, and Webster soil series in Iowa to determine which soil, management, and weather factors affected corn yield responses to applied fertilizers. Nitrifiable N, soil test P and K, and pH significantly affected unfertilized yields and yield responses to N fertilizer. Plant density and moisture stress index also affected responses to N. Similar results were obtained by Desselle (1967) from experiments located on the deep loess soils in Iowa.

Voss et al. (1970) studied the response of corn on the Marshall and Monona soils in western Iowa to NPK fertilizer rates, soil test levels, plant density, environmental factors, and moisture stress. Because of severe moisture stress in 1 of the 2 years, the corn yield response to N fertilizer was markedly affected by moisture stress. However, many of the other variables affected corn yield and responses to fertilizer nutrients.

Christensen (1968) found that the response of corn to applied P was influenced by both the surface and subsoil soil test P levels. A greater response to applied P was obtained at low pH values (5.5) because of lower availability of the soil P.

Hanway et al. (1962) found that corn yields were increased significantly by K fertilizer in only 11 of 41 field experiments in six north-central states. Uptake of K fertilizer as shown by plant analyses was inversely proportional to the soil test K level. They concluded that the effect of applied K fertilizers on K concentration in the plant and corn grain yield was related to the available K level in the soil.

Although rates of fertilizer have the largest effects on corn yield, their effects may be modified by times and methods of application. The time of application primarily affects the responses to N fertilizer because it is a mobile nutrient (can be leached if in the nitrate form). Meyer (1973) reviewed the literature on time of N application. His research showed that spring-applied, pre-plant N gave larger responses than fall-applied N although the differences varied with the amount of rainfall in the fall and following season. Side-dressed N was slightly more efficient than spring pre-plant N. The effect of time of N application on corn yield was not determined in this study although the variable was included for future study.

Casanova (1979) reviewed extensively the research on methods of P application, including broadcast and plowing under, broadcasting and disking in, and row fertilization. Dumenil et al. (1965), Voss and Herman (1967), and Voss et al. (1974) have discussed the advantages and disadvantages of broadcast and row application of P and K fertilizers. In his study of the effects of broadcast rock phosphate and superphosphate and row applied fertilizer, Casanova (1979) found that the responses to broadcast superphosphate and row fertilizer were affected by the presence of the other, plant density, and climatic variables of heat unit accumulation and moisture stress. Broadcast P gave larger responses than the row fertilizer. Combinations of broadcast P and row fertilizer appeared more profitable than either one in eastern Iowa but the broadcast P was more profitable than row fertilizer or the combination of the two in northcentral and northwestern Iowa.

Results from most experiments show that the effects of K placement on corn yield are similar to those of P placement. Because K uptake by corn up to silking occurs at a faster rate than that of either N or P, hill or row placement and broadcasting and plowing under may be more important for K than for P.

The methods of broadcast P and K application, although included as variables for future use, were not analyzed in this study. The row fertilizer variable, however, was included in the regression analyses.

Henao (1976) included total N, P, and K (total nutrients from manure and all fertilizers) in his multiple regression models of corn yield on soil, management, and weather variables. Because of the constant ratio of nutrients in manure and because many farmers used similar ratios of N, P, and K in their fertilizer applications, the simple correlations between total nutrients were high ($r_{N,P}$ = 0.69, $r_{N,K}$ = 0.53, and $r_{P,K}$ = 0.80). These high correlations caused distortions in the regression coefficients of the applied nutrient variates and complicated the interpretation of the variable effects. In his final model, however, total N had a positive, curvilinear effect on corn yield up to the rate that gave maximum yield; its effect was modified by significant interactions with crop sequence (rotation), soil test N level, and moisture stress. Total P had a significant linear effect on yield modified by soil test P level and percentage clay in the plow layer. Total K had a slight, negative effect on yield but its effect was distorted by the high correlation with total P.

Using data from western Iowa counties, Pena-Olvera (1979) included N and P fertilizer variables (r = 0.62) in his final regression model. Both had linear effects on yield. The effect of N fertilizer was modified by interactions with crop sequence and organic carbon of the plow layer and that of P fertilizer by interactions with soil test P of the plow layer and drainage class.

Crop rotation   The effects of crop rotation on corn yields have been studied in many experiments. Shrader and Voss (1980) reported that crop rotation affects fertility needs, soil erosion, soil properties, and insect, weed, and disease infestations and control. Well-inoculated legume crops grown in rotation have been recognized as important sources of N for grain crops. Yields of rotation corn consistently exceeded those of continuous corn. The cause is not known, but lower maximum yields of continuous corn may be due to insects such as corn rootworm, to unidentified disease problems, or to increased soil compaction.

Higher soil bulk density at the 15 cm depth in continuous corn than in corn in a corn-oat-meadow-meadow rotation was reported by Hageman and Shrader (1979). The soil organic matter content was also higher with crop rotation. Schmid et al. (1959) reported that N was the most important single factor influencing yields of corn following meadow, small grain, and soybeans. Crop rotation also affected available K in the soil because different amounts of K were removed by harvested crops.

Henao (1976) included crop rotation codes for both N availability and K availability in his yield regressions. The N rotation code had a significant curvilinear effect on corn yield and had significant interactions with soil test N in the plow layer, total N nutrient application, and moisture stress index. Pena-Olvera (1979) reported a linear yield response to N rotation code modified by significant interactions with N fertilizer, bottomland landscape position, and moisture stress index.

Residual N, P, K fertilizers   Grain crops usually do not remove more than half of the N and one-fourth of the P and K fertilizers provided the stover or straw is left in the field (Pesek and Dumenil, 1955). In Iowa soils the residual effect of N fertilizer is usually evident in the second year after application, and that of P and K fertilizer is evident for several years after application (Dumenil et al., 1959, 1960). White and Pesek (1959) reported that the residual N applied one year previously appeared to be chiefly in the form of nitrates below the plow layer.

Different sources of P were evaluated by Webb and Pesek (1954) who showed that ordinary superphosphate, concentrated superphosphate, and calcium metaphosphate applied at equal rates over a period of years had similar effects on the residual level of available P and on the yield of oats. The residual effects of broadcast K fertilizer for corn on the next year's corn crop were relatively large on soils deficient in K (Dumenil et al., 1959). The yield responses to residual K fertilizer the second year following application were only slightly smaller than the responses in the year of application.

Manu (1979) included variables for the residual effects of N the first year after application and of P for 1, 2, and 3 years after application in his yield regressions. Only P applied one year previously had a significant effect on yield in the final model; it also had a significant interaction with soil test P of the 76-106 cm (30-42 in.) layer.

<u>Tile</u> Tile drainage of somewhat poor to poorly drained soils is common in Iowa. The effects of tile depth and spacing on corn growth and yields in various experiments have been reviewed by Schwab (1966).

Drainage increased corn yield but the effects of tile depth and spacing varied with soil type. In Iowa the 10-year average yield on Webster silty clay loam was 2 bushels per acre higher for the 100-foot than for the 200-foot spacing. On Edina silt loam in southern Iowa, the average corn yield was higher for the 15-foot than for the 30-foot and 60-foot tile spacings. The variability in yields from year to year, largely due to climatic factors, was much greater than differences due to tile spacing in a given year.

Henao (1976) showed a highly significant, linear yield response to tile distance. The closer the distance to the tile line, the higher was the yield. The tile distance had no interactions with other variables.

Soil tests of the plow layer

The soil pH and available nutrients of the plow layer originally reflected the natural processes of soil development. In more recent years in Iowa and much of the United States, they have reflected primarily the effects of management including liming, heavier fertilization, greater crop removal of nutrients by higher yields, and nutrient losses by accelerated erosion.

For many years, researchers developed and tested in the laboratory and greenhouse many soil test methods to estimate the plant-available nutrients in the soil. The soil test values were then correlated with crop responses to determine the best methods for estimating the fertilizer rates needed to optimize production of many different crops. Much of the earlier research involved only one or two nutrient variables and limited ranges of soil and climatic conditions. The many contributors in Walsh and Beaton (1973) have extensively reviewed the literature about soil testing and the relationships among soil tests, fertilizer and lime usage, and crop yields.

More recently, more complex experiments covering wider ranges of soil and climatic conditions have been conducted (Hanway and Dumenil, 1955; Dumenil, 1958; Dumenil et al., 1959; Voss, 1962; Desselle, 1967; Christensen, 1968; Voss, 1969; Casanova, 1979). In these studies, corn yields from many experiments were related to fertilizer rates, soil test levels, some management and soil variables, and climatic factors in some cases using quadratic functions and interactions in multiple regression analyses. The soil test pH, N, P, and K levels influenced optimum fertilizer rates and these relationships often were influenced by other variables through interactions. For this study, the soil test variable effects will be discussed from recent research on the relationships between corn yields, and soil, management, and climatic variables (Henao, 1976; Pena-Olvera, 1979; Manu, 1979).

Soil pH and buffer pH The acidity of the surface soil in Iowa varies among and within soil types. Most soils test slightly acid (pH 6.0-6.2) because of previous liming except those in the Clarion-Nicollet-Webster and Monona-Ida-Hamburg soil association areas where most of the calcareous (high-lime) soils occur (Voss et al., 1965).

Both soil pH and buffer pH are measured by the Iowa State University Soil Testing Laboratory. The buffer pH has been calibrated with the amount of limestone needed to change the soil pH to 6.5 and 6.9 and limestone recommendations are based on these calibrations. Because of the high correlation between soil pH and buffer pH, only one of these variables should be included in the regression at a time (Henao, 1976). The soil pH is preferable because it can explain corn yield variations as the pH increases from 7.0 to 8.2. The buffer pH has a limit of about pH 7.0 as the soil pH increases above 7.0. Henao (1976) showed that the R^2-values in the alternative regression models comparing soil pH and buffer pH, however, were almost the same.

Pena-Olvera (1979) in the intercorrelation analysis by latent root and vectors showed that there was a dependency among pH of the plow layer, depth to minimum pH, depth to the calcareous horizon, subsoil P levels, drainage class, site location, landscape location, erosion class, and subsoil K levels. His study included sites from western Iowa, few of which were very acid or had been limed. In eastern Iowa, liming has changed the intercorrelations involving pH of the surface and soil variables.

The soil pH variable had a curvilinear effect on corn yield in all final models of previous investigators (Henao, 1976; Manu, 1979; Pena-Olvera, 1979). Soil pH of the plow layer was involved in interactions with soil biosequence and soil test N (Henao, 1976), silking date, subsoil structure, and percent clay in the plow layer (Pena-Olvera, 1979), and total P application and soil test P level (Manu, 1979).

<u>Soil test N, P and K</u> Soil test values are an index of nutrient availability and not the actual pounds of the nutrient per acre available to a given crop. Their effects on yield will vary with the

environment, soil variables, available nutrients in the subsoil, weather, and management variables.

Henao (1976) reported that soil test N was correlated with organic carbon content of the plow layer (r = 0.46), soil test P was correlated with subsoil P (r = 0.43), and soil test K was correlated with range or E-W direction (r = 0.55), bulk density (r = -0.46), and subsoil K (r = 0.62).

The intercorrelations studied by Pena-Olvera (1979) showed that the soil test variables were involved in several of them. One of the intercorrelations showed a dependency between soil test N, soil test P of plow layer and subsoil, organic matter related variables (organic carbon content, slope, and erosion class), and landscape position. Another showed a dependency between soil test P, slope, erosion class, drainage class, and percentage clay of the plow layer. Another intercorrelation showed the relationship between soil test K, subsoil K, slope, and pH of the subsoil. The final one showed relationships between soil test P and K levels in both the plow layer and subsoil, slope, erosion class, minimum pH in the subsoil, and depth to calcareous layer. These intercorrelations show that the yield - soil test variable relationships are indirectly affected by many soil and location variables.

Henao (1976) found in his final prediction model that both soil test N and soil test P had significant curvilinear effects on yield but soil test K had only a linear effect on yield. Both Pena-Olvera (1979) and Manu (1979) reported linear responses of yield on soil test N and curvilinear responses on soil test P levels. The soil test K variables had no effect on yields in the western Iowa soils because most had high soil test K levels.

Soil test N was involved in significant interactions with total N application, crop sequence (rotation), erosion class, and organic carbon content of the plow layer (Henao, 1976), organic carbon and bottomland landscape position (Pena-Olvera, 1979), and years contour planted, years terraced and N code for crop rotation (Manu, 1979). Soil test P had significant interactions with corn rootworm damage, total P application, depth to minimum pH in the subsoil, and moisture stress (Henao, 1976), P fertilizer application, soil organic carbon, and moisture stress (Pena-Olvera, 1979), and pH of the plow layer and N code for crop rotation (Manu, 1979). Soil test K had a significant interaction only with biosequence (Henao, 1976). All of these interactions show that the yield - soil test variable relationships are complex.

Climatic Variables

Climate has long been the subject of much research to explain its effect on yield variation. Its influence on crop growth and yield production is very dependent on different soil characteristics and management variables. The effects of climatic variables, particularly moisture stress, have been mentioned many times previously.

Consideration of weather involves both selection of climatic variables and the time periods over which daily weather records are integrated. Morris (1972), Henao (1976), and Pena-Olvera (1979) have reviewed extensively most research on climatic variables and development of weather indexes. Some of the important information relating to this study will be presented here.

Precipitation and temperature of different intervals have been used as variables in corn yield regressions. Laing (1966), however, concluded that such variables were not directly related to the production processes limiting crop yield and that the relationships were not adequately described by the models proposed.

The amount of available soil moisture in the crop root zone has been considered a more rational and direct parameter for evaluating the effects of climate on agricultural growth. Several workers, including Parks and Knetsch (1959), Gardner (1960), Denmead and Shaw (1962), and Baier and Robertson (1968), have shown that the loss of soil moisture is a joint function of the atmospheric energy, which causes evaporation from the soil and plant surfaces, and the soil moisture available to supply this atmospheric demand.

Denmead and Shaw (1962) experimentally expressed the amount of soil moisture in the corn root zone at an estimated turgor of plant leaves, called turgor loss point (θ_{TL}), as a function of the evapotranspiration at field capacity (ET_{FC}). Dale and Shaw (1965a), in a study on the effect of moisture stress and stand level on corn yield, identified any day in which the evapotranspiration at field capacity (ET_{FC}) and the available soil moisture (θ) combination fell below the turgor loss curve, $\theta_{TL} = F(ET_{FC})$, as a moisture stress day for corn. This is a day which has too little soil moisture to counteract a high atmospheric demand ($\theta < \theta_{TL}$). A day with ET_{FC} and θ combination falling on or above the curve was identified as a nonstress day ($\theta \geq \theta_{TL}$).

Other Iowa studies (Voss and Pesek, 1967; Dale, 1968; Corsi and Shaw, 1971; Shaw and Felch, 1972; Shaw, 1974) have shown that a soil moisture budget and plant-soil-moisture relationship, as described by Dale and Shaw (1965a, 1965b), gave an adequate index for relating soil moisture, atmospheric demand, and plant yield for most of the environmental conditions prevalent in Iowa.

Besides the relationship between yield reduction and moisture stress, numerous researchers have shown that excess moisture or wet soil conditions may also reduce yield, particularly if excess moisture occurred early in the season. Ritter and Beer (1969) concluded that, under some natural flooding conditions, corn plants in the early stages of growth will be completely killed by inundation periods of 4 to 5 days. Lal and Taylor (1969) found that corn yields were depressed by either shallow water tables (6 to 12 inches) or intermittent flooding.

Chaudhary et al. (1975) studied the effect of water table depth and soil submergence on corn yield and nutrient uptake. They showed that a water table at 24 to 36 inches deep was a valuable natural resource for corn production in a relatively dry year, but hazards of poor aeration increased in a wet year. Grain yields were reduced significantly by submergence exceeding one day. Submergence during early growth was more harmful than during late growth. Prolonged soil submergence significantly reduced N, P, and K concentrations in the grain.

Shaw (1974) pointed out that, in some Iowa soils, excess spring moisture would be expected to give substantial reductions in yield depending on how much water occurred and the level of management. Morris (1972) made an extensive review of the literature concerning the physiochemical effects of wet conditions on soils and plants. He derived excess moisture indexes along with moisture stress indexes described by Dale and Shaw (1965b) by using a simulated model for rainfall infiltration, redistribution throughout the soil profile, and moisture balance in the soil depending on atmospheric demand. The weather indexes selected and the interactions of these indexes with selected soil and management variables were important in explaining corn yield variations. Henao (1976) and Pena-Olvera (1979) then modified these indexes.

<u>Soil moisture stress index</u>

In his modification of the computer program described by Dale and Shaw (1965b), Morris (1972) tested 3 different stress indexes. The first was the nonstress day index (NSD). This was made by dividing the greater of either (1) the root zone moisture percentage or (2) the surface foot moisture percentage by the moisture percentage obtained from the turgor loss function for the prevailing atmospheric demand and summed for the index period. If the quotient (RATIO) was greater than 1.0, a nonstress day was assumed. This test formed the basis for the nonstress day index:

$$NSD = \Sigma q, \qquad \text{where } q = 1 \text{ if RATIO} > 1.0$$
$$= 0 \text{ otherwise.}$$

The second stress index was 1 - RATIO, which was:

$$1 - \text{RATIO} = \Sigma(1.0 - \text{RATIOP}), \quad \text{where RATIOP} = 1.0 \text{ if RATIO} > 1.0$$
$$\text{RATIOP} = \text{RATIO otherwise.}$$

This method included the intensity of stress in an index.

The third index had a different method for its computation. This method of obtaining a measure of the relative efficiency of the net photosynthetic processes was to sum the relative transpiration ratios for each day in the index period (63 days or from six weeks before to 3 weeks after the 75 percent silking date). The relative transpiration ratio was determined from the relationship given by Shaw (1963) which was based on the greater of the PAWC percentage for the root zone or for the surface foot and the atmospheric demand intensity as given by the daily pan evaporation value. This index was designated DEFCT by Morris (1972).

The three indexes (NSD, 1 - RATIO, and DEFCT) were then modified by using a weighted value for growth stage. These indexes were called NSDW, (1 - RATIO)W, and DEFCTW. The weights were derived principally from observation of stress impact on yields as found by Claassen and Shaw (1970) and shown in graphical form by Morris (1972). The other weighting factor which was tested, energy weight, was applied to the indexes along with the growth stage weighting factor. The energy weights were estimated from daily pan evaporation losses. These indexes were called X1, X3, and DEFCTV. The X1 index was the 63-day summation of stress evapotranspiration weighted for growth stage, and was similar to DEFCTV except that the latter was multiplied by a growth stage evapotranspiration adjustment factor obtained from the relation given by

Shaw (1963). X3 corresponded to weighting 1 - RATIO for energy; because 1 - RATIO was negatively associated with yield, X3 was calculated by weighting RATIOP to produce a positive correlation with yield.

From his analysis comparing these indexes, Morris (1972) concluded: (1) the indexes weighted by daily pan evaporation loss and growth stage factor (X1, X3, DEFCTV) were more strongly associated with yields than the unweighted indexes or those weighted only by a growth stage factor only, and (2) the indexes based on relative transpiration ratios, viz., DEFCT, DEFCTW, and DEFCTV generally were superior to indexes based on RATIO or RATIOP, viz., NSD, NSDW, X1, 1 - RATIO, (1 - RATIO)W, and X3. Little difference was found between the moisture stress variables, DEFCTV and X1; DEFCTV, however, was chosen as the moisture stress variable in his regression analysis.

Henao (1976), after some modifications of the input data, modified the program to compute the following indexes, X3, DEFCT, DEFCTV, DEFCTW, and DEFCTX, where DEFCTX was weighted for energy (daily pan evaporation) only. He then used abbreviated symbols, DT for DEFCTV, DV for DEFCTV, DW for DEFCTW, and DX for DEFCTX. A precipitation variable (P75) which was the sum of the total rainfall in the 75-day growth period starting six weeks before the silking date was also calculated. The DV index was very highly correlated with DX and X3 and somewhat less so with DW and DT which were unweighted for pan evaporation. DW and DT also were very highly correlated. P75 had less correlation with all other stress indexes (r = 0.49 to 0.57). Henao (1976) showed that, in general, the moisture stress indexes weighted for both growth stage and pan evaporation loss (X3 and DV) were more strongly correlated with yields than the others. DV was selected as the moisture stress index to include in his yield regressions.

Pena-Olvera (1979) used DV for his study and made some modifications of the input data as well as in the soil moisture program itself. The five modifications that he made were: (1) reestimation of PAWC, (2) use of a 75-day instead of a 63-day index period, (3) use of the growth stage weighting factor presented by Shaw (1974), (4) reestimation of starting plant available water (PAW), and (5) use of water runoff corrections by slope, previous crop, and/or infiltration. His reestimation of PAW included modifications for antecedent rainfall and water runoff.

Pena-Olvera (1979) then tested different combinations of these modifications in alternate regression models. His results showed that DV3 and DV4 were superior to the others. DV3 was DV (Henao, 1976) with the first four modifications listed in the previous paragraph. DV4 was similar to DV3 except that the reestimated PAW was corrected by antecedent rainfall. Substitution of DV4 for DV3 in the regression model increased the R^2 only from 0.6828 to 0.6835. This was very little improvement in the R^2-value for the amount of work to correct PAW for antecedent rainfall.

For his final yield prediction model, Pena-Olvera (1979) included DV4 as the moisture stress index. It had a highly significant linear effect on corn yield modified by significant interactions with subsoil permeability, subsoil root rating for root growth, plant available water capacity, plant density, weed infestation, planting date, silking date, crop sequence (rotation), and soil test P of the plow layer.

Henao (1976) using statewide data found that DV also had a linear effect on yield modified by significant interactions with plant density, first brood corn borer, total N applied, rotation, soil test P of the plow-layer, plant available water capacity, and soil biosequence.

Excess moisture index

Morris (1972) incorporated into the soil moisture computer program the derivation of three basic types of excess moisture indexes. The first index, designated MOISDY, was computed by summing the number of days any layer in the root zone was above field capacity. The total was taken for a 46-day period beginning three days after planting.

The second index was computed by finding the fraction of the root zone in which the layer air space was estimated to be less than 10 or 15 percent by volume and summing these fractions for the same period as used for MOISDY. These indexes were called EXMO2 and EXMO3 for the 10 and 15 percent criteria, respectively. These indexes were also weighted by growth stage. The weighting used was based on data of Ritter and Beer (1969) and modified by Morris (1972). Because the weighted indexes were more highly correlated with yield, use of the unweighted indexes was then discontinued. EXMO1 and EXMO4 were added later to the program with the criteria of 7.5 and 12.5 percent air space, respectively.

The third index was designated AIRVOL, which was the sum of the surface layer air space for a 21-day period starting three days after planting. After testing these derived indexes, Morris (1972) retained the weighted EXMO2, EXMO3 and EXMO4 indexes in the soil moisture program.

Henao (1976) modified the soil moisture program and computed the excess moisture indexes by finding the fraction of the root zone in which the layer airspace was estimated to be less than 12.5, 15.0 and 17.5% by volume for EXMO2, EXMO3, and EXMO4, respectively. These indexes were also weighted by crop growth as used by Morris (1972). He also calculated EXMO3V, which was EXMO3 weighted by energy based on pan evaporation losses. Henao abbreviated the symbols of these indexes by using EM2, EM3, EM3V, and EM4 for the EXMO2, EXMO3, EXMO3V, and EXMO4, respectively. These indexes were tested in alternate regression models along with management and soil variables. EM3V was selected to be included in his final prediction model.

Pena-Olvera (1979) modified the EM3V indexes in the same way that he modified the moisture stress indexes, as described in the previous section. For his final model, he selected EM34 along with DV4 as the weather variables in the regression of corn yield on soil, management, and weather variables. The EM33 index, not corrected for antecedent rainfall, was almost perfectly correlated ($r = 1.000$) with EM34 which was corrected for antecedent rainfall.

Both Henao (1976) and Pena-Olvera (1979) found that the excess moisture index had a significant, negative, linear effect on corn yield. However, no significant interactions occurred between the excess moisture index and other variables.

Soil Variables

The influence of soils on crop production varies because of differences of their physical and chemical properties. Variations of parent material, biological influences, climatic conditions, topography, and time of development among Iowa soils have resulted in many different soil series grouped in many different soil associations (Oschwald et al., 1965). The differences of soil properties and their combined effect on crop yield have caused differences in the productivity levels of Iowa soils (Fenton et al., 1971). The combination of soil variables, known to influence yield production, together with management and climatic variables, should improve the corn yield regression model. Henao (1976) and Pena-Olvera (1979) reviewed extensively the effects of different soil variables and their interactions on yield. Variables related to location, soil organic matter, soil texture, soil pH, and parent material reported to influence corn yield by other researchers are examined in this study.

Location variables

The long-term climatic effects have caused differences in soil properties across Iowa. Salih (1980) reported a high correlation between legal township number (S-N direction) and mean annual temperature ($r = -0.96$), and between legal range number (E-W direction) and mean annual precipitation ($r = -0.85$) although precipitation decreases generally from southeast to northwest Iowa. Township and range numbers therefore can be expected to estimate the long-term climatic effects on soil properties in corn yield regressions.

Both the township and range variables had significant curvilinear effects on yield (Henao, 1976). Yield increased to a maximum at about Township 73N (north edge of the second tier of counties from the Iowa-Missouri border) and then decreased from south to north across Iowa. Yield decreased from east to west to a minimum at about Range 29W (eastern edge of Greene County) and then increased. He did not include any interactions involving the township and range variables. Henao reported that the range variable was highly correlated with bulk density because of more till soils in eastern and central Iowa and more loess soils in western Iowa. The subsoil pH was also highly correlated with range which reflected the decrease of leaching and weathering from east to west. Deletion of the township and range variables from the final yield model reduced the R^2 slightly and markedly increased the significance of clay content of the plow layer, subsoil K, and interactions between clay and biosequence, minimum pH and depth to minimum pH, and depth to minimum pH and subsoil K.

Organic matter group of variables

In the organic matter group of variables were erosion class, thickness of A horizon, and organic carbon content of the surface 0-51 cm. These variables are highly intercorrelated. Manu (1979) has extensively reviewed the effects of these variables on corn yield.

Henao (1976) reported that organic matter variables were interrelated with other soil variables such as slope, slope configuration, drainage class, and biosequence, either directly or indirectly through the effects of the latter group of variables on organic matter accumulation or losses. The correlations between erosion class and thickness of A horizon and soil organic carbon were higher in southern and western Iowa than in central or eastern Iowa. He reported that erosion class had a direct effect on yield. Its significant indirect effects were through plant available water capacity, depth of A horizon, percentage clay in the plow layer, maximum clay, organic carbon and available P in 76-107 cm (30-42 in.) layer. The effects of the erosion, thickness of A horizon, and organic carbon content variables in Henao's final prediction model were modified by interactions with soil test N in the plow layer, plant available water capacity, and minimum pH in the subsoil.

Texture group of variables

Soil texture describes the particle size distribution present in the soil. Its influence on crop growth and yield is obvious through its influence on soil properties such as plant available water capacity, drainage, aeration, root penetration, and available nutrients.

Soil variables such as percentage of clay in the plow layer, maximum percentage of clay in the subsoil, and the depth to the layer with maximum clay and others such as soil bulk density, plant available water capacity, drainage class, and subsoil group rating for root growth which are related to texture may be included in the yield regression model. All of these variables together with the parent material classes were involved in one or more strong intercorrelations (Pena-Olvera, 1979). Each variable in the yield regression, therefore, must be tested if the effects of high correlations between variables need to be reduced.

Drainage class of the soil profile, percentage clay in the plow layer, and plant available water capacity were included in the final prediction model of corn yield on management, climatic, and soil variables by Henao (1976). Drainage had a highly significant curvilinear effect on yield with maximum yield occurring on the moderately-well drained soils. The percentage clay in the plow layer had a positive linear effect on yield modified by an interaction with P fertilizer application. Plant available water capacity had a positive linear effect on yield modified by interactions with moisture stress index, thickness of A horizon, and organic carbon content of the plow layer.

Soil pH group of variables

Soil pH influences plant growth and yield through its influence on the soil chemistry, especially that related to the availability of plant nutrients in the soil. The optimum pH for nutrient availability is between pH 6.5-6.8 for corn production. Mosavati (1979) presented a detailed review on subsoil acidity in Iowa soils. He studied the factors influencing minimum pH and depth to minimum pH in the subsoil horizons of Iowa. Variables related to parent material classes, organic matter (slope, thickness of A horizon and organic carbon content), texture (clay content, drainage, bulk density, and depth to maximum clay), and location (township and range) were those that affected the minimum pH and the depth of minimum pH in the subsoil.

Soil test P in the subsoil layers is influenced by soil pH. Salih (1979) showed that soil test P in the 76-107 cm (30-42 in.) layer had a curvilinear response on soil pH of the same layer. The effect of soil pH on subsoil P was modified by interactions with organic carbon content, parent material variables, township, and biosequence. Factors which affect soil test P will also affect the yield.

Variables such as minimum pH, depth to minimum pH, depth to the calcareous horizon, and pH and soil test P of the 76-107 cm (30-42 in.) layer, therefore, were tested in this study. Henao (1976) included in his final prediction model the minimum pH, depth to pH minimum, and soil test P of the 76-107 cm layer. All had significant linear effects on yield. The effect of minimum pH in the profile on yield was modified by interactions with slope, thickness of A horizon, organic carbon level, and subsoil P level. The depth to minimum pH variable had an interaction with soil test P in the plow layer on yield and soil test P in the subsoil had an interaction with minimum pH.

Parent material variables

The principal parent materials of Iowa soils are (1) glacial drift, (2) loess, and (3) alluvium. Approximately 95 percent of Iowa soils formed from one of these three parent materials. The remaining 5 percent formed from colluvium, limestone, sandstone and shale residium, and organic deposits (Oschwald et al., 1965). If any soil physical and chemical characteristics, including availability of plant nutrients, are different due to differences in the parent material and differential weathering, the parent material variables should be included in the yield regressions.

Salih (1979), Ghaffarzadeh (1979), and Mosavati (1979) reviewed the literature on the effects of different parent materials on the subsoil P, K, and pH levels, respectively. They also reported that parent material variables and their interactions with other soil variables had significant effects on subsoil P, K, and pH.

Using dummy variables to distinguish between one parent material and the others, Henao (1976) included in his study the following parent materials: till, paleosol or gumbotil, loess <150 cm (60") over till, loess >150 cm deep, <150 cm to sand, <150 cm to bedrock, alluvium in stream terraces, and alluvium in bottomlands. None of the parent materials, however, was included in his final prediction model nor were any interactions tested. Some of the parent materials were correlated with plant available water capacity, bulk density, excess moisture index, thickness of A horizon, and average clay content.

Miscellaneous soil variables

Other soil variables which influence yield are biosequence and soil test K of the subsoil; these were tested in this study. The biosequence variable which characterizes the soil development under forest, forest-prairie, and prairie vegetation has an effect on other soil variables and yield. Henao (1976) reported a highly significant linear effect of biosequence on yield with the prairie soil giving the highest yield. The biosequence effect was modified by interactions with soil pH and soil test K of the plow layer, and with the moisture stress index.

Ghaffarzadeh (1979) reported that many variables influenced the available K in the subsoil horizons of Iowa soils. Henao (1976) reported some significant linear effects of available K in the 30-61 cm (12-24 in.) layer on yield in his preliminary models, but this variable was not retained in his final prediction model because of the high correlation with soil test K of the plow layer ($r = 0.62$).

MATERIALS AND METHODS

Description of the Research Project

The basic data used for this study were the same as the data that were used by Henao (1976) for all counties and Pena-Olvera (1979) for the western counties in Iowa. Corn yield, soil, climatic, and management data were collected under the supervision of Dr. Lloyd C. Dumenil of the Agronomy Department for the Iowa Agriculture and Home Economics Experiment Station Project 1377 (replaced by Project 1958 in 1972 and then Project 2326 in 1978). Cooperating in the field phases of the project were the Iowa Cooperative Extension Service, the Soil Conservation Service, USDA, and many farmer-cooperators and volunteer rainfall observers. The title of the project was: Crop yielding capacity of Iowa soil types under different soil, management, and fertility levels.

The primary objective of this project was to determine for the various soils of the state the crop yield level that is attainable under different management, environmental, and climatic conditions. The experimental method employed was point-estimate sampling in which the crop yield was determined at randomly selected sites (one plot per site) in selected Iowa counties; all environmental, climatic, soil, and management variables that could affect the crop yield at that specific site were measured or estimated. The statistical method of multiple regression was used to relate the yield of a crop to the level of input of a number of variables which are known or thought to influence crop yields.

The project was initiated in 1957 in two counties and counties were added each year until 1962 when the fifteenth county was added. The years when the research was started and the distributions of the yield observations over years are given in Table 1. The field research was terminated after the 1970 season.

Table 1. Year started and distribution of observations over years in the 15 counties included in the project from 1957 through 1970

County	Year started	Number of observations			
		Through 1963	1964	1965-1970	Total
Hamilton	1957	129	16	53	198
Wayne	1957	64	12	35	111
Adams	1958	51	9	45	105
Cass	1958	99	18	72	189
Clay	1958	132	14	51	197
Keokuk	1958	113	23	61	197
Bremer	1958	92	10	49	151
Harrison[a]	1959	78	21	95	194
Woodbury	1959	142	20	86	248
Muscatine	1959	86	11	67	164
Crawford	1960	94	28	89	211
Lyon	1960	90	22	92	204
Fayette	1961	62	20	104	186
Linn	1961	66	20	107	193
Howard	1962	27	11	71	109
Total		1325	255	1077	2657

[a]Upland and local bottomland sites were first sampled in 1959 but Missouri Bottomland sites were not sampled until 1963.

The 15 counties (Figure 1) were selected to represent major soil association areas in the state, all of which were represented except the Adair-Grundy-Haig area in southern Iowa. Within each of the selected counties, the 2% sample of quarter-sections for the Conservation Needs

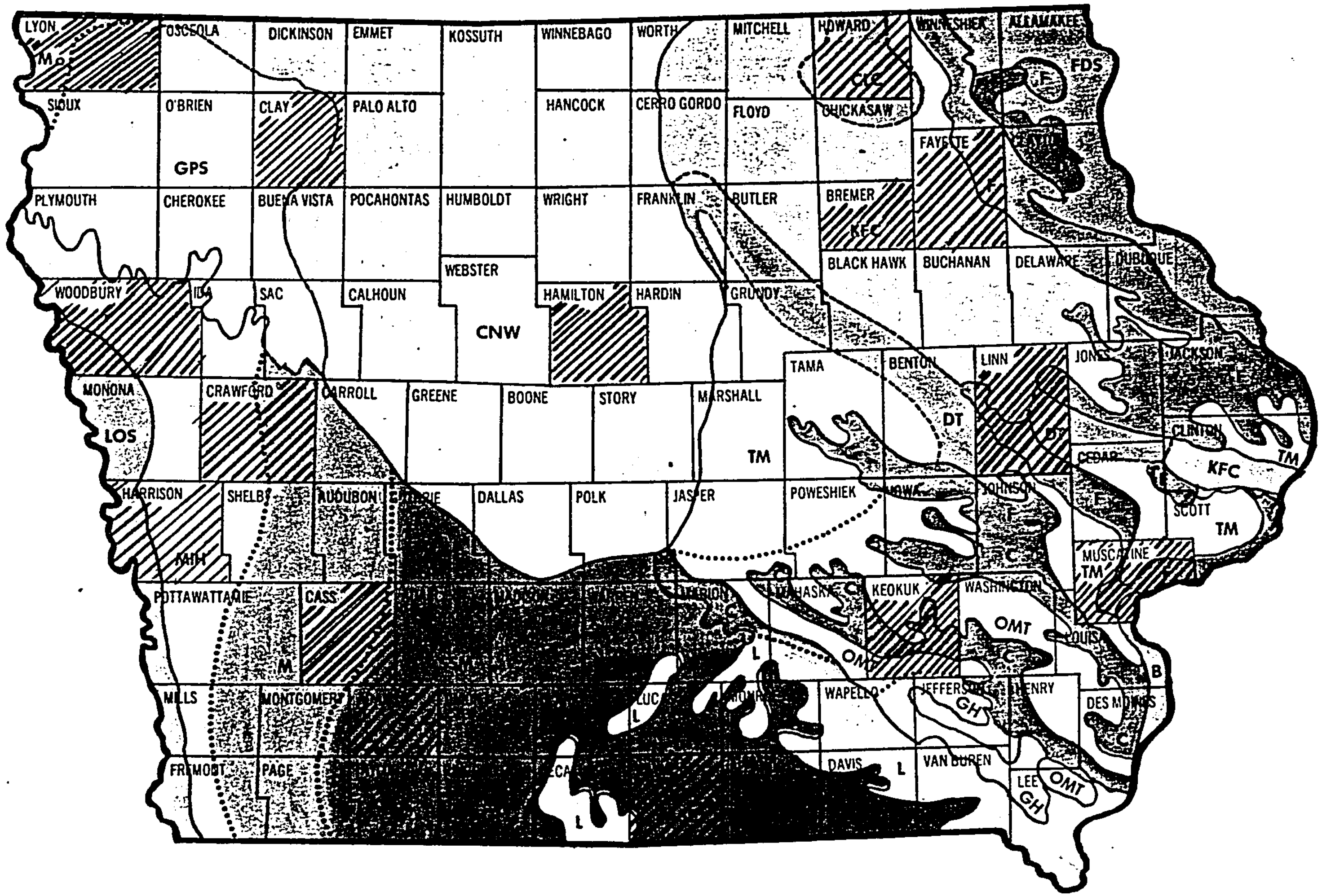


Figure 1. Iowa counties (marked by diagonal lines) included in Project 1377 in relation to soil association areas (map from Oschwald et al., 1965)

(Soil Inventory) Survey was used for location of sites used in this research. For the Conservation Needs Survey, three quarter-sections per legal township were selected by semistratified, random sampling. In each of these quarter-sections a single site was randomly selected, as described by Henao (1976). The site selected was retained for as long as it was needed. A few sites, however, were relocated within the quarter-section, mostly because of loss of access.

Yield was checked each year the site area was planted to corn unless severe hail damage occurred, the corn was cut for silage or harvested before yields could be measured, or the cooperator did not report that corn was planted on the site. Data were also collected on the soil and site characteristics, crop and soil management of the farmer-cooperator, and rainfall at or near the site.

Some sites were discontinued each year, particularly in the last several years in the counties which were sampled the earliest, to reduce the work load and expenses. Sites were dropped for several reasons, as follows: loss of access; noncooperation of the original farmer or the new owner or tenant; destruction of the site area or its uniformity by building, road, or terrace construction, haystacks, or hog lots on the site area; conversion to permanent pasture; loss of rainfall observers; and continued low management levels. The reduction in number of sites had little or no effect on the primary objective of the project, which was to study the relationships between yield and other factors over a wide range of conditions.

Yield, Field, and Management Data

Data for yield and the field and management variables, most of which were included in this study, were punched originally on the three computer cards shown in Appendix Tables A1, A2, and A3. The descriptions of the variables used both in the preliminary and final analyses will be given in the following sections.

Preharvest

Prior to 1961, the sites were located in the fall for harvest except for those that had been located for the first time in July or August by the Soil Scientists who sampled and described the soil profiles. From 1961 on, the sites were located in June or early July so that the 75% silking dates could be determined and leaf samples collected for chemical analyses much faster. At this time, plots were accurately located and staked, average row widths and hill spacings were measured, initial plant counts were made, notes were recorded about growing conditions and management practices to aid in interpreting results or in clarifying certain management practices, and directions were recorded for locating the plots at later visits.

The plots were usually checked two or more times during silk emergence to count the number of plants having silk emergence on the primary ear shoot. From these silking counts every 2 to 3 days, the 75% silking date (SLKDATE) was estimated. Silking dates prior to 1961 were estimated from observations by the farmer-cooperators and from the grain moisture at harvest, since many of the plots were harvested at or shortly after physiological maturity. Also, at the time of silking, total plants were recounted and notes were made on nutrient and moisture stresses, weed infestations, hail damage, and varieties if more than one could be identified in or near the site area.

Corn yield data

The yield of corn (Y or YIELD, the dependent variable in the yield regressions) was determined at each site by hand-harvesting and weighing the ear corn from about a 1/100 acre (1/250 hectare) plot. A grain sample for moisture determination was obtained by removing two rows of kernels from about half of the ears; the grain was then stored in a moisture-proof bag. The grain moisture was determined later by weighing a 300-gram sample, drying 48 hours at 65°C, reweighing, and calculating the moisture content. The yield was then calculated as bushels per acre of shelled corn at 15.5% grain moisture (No. 2 corn) using standard conversion factors (Dyas, 1956) and later was converted to quintals per hectare. If the corn was immature or of low quality, 10 to 15 pounds of ear corn were dried and shelled and the yield per acre was calculated from the weight of the shelled corn adjusted to 15.5% moisture; this latter procedure was more accurate than the first one but was impractical for the large number of sites harvested each year.

The yields of hail-damaged and disease-damaged corn were adjusted to a zero-damage basis by the methods described by Henao (1976). If the corn had to be harvested before physiological maturity, the yield was adjusted upward to account for this yield loss (Henao, 1976).

Estimated yield loss, expressed as a percentage, due to frost or freeze damage (FROST) in the fall was calculated from the difference between date of frost or freeze damage and date of physiological maturity, using the same assumptions as for the yield loss due to harvesting before physiological maturity (Henao, 1976).

The average ear weight per plant (EARWT) was computed as follows: average ear weight (lb/acre) = (adjusted yield * 68.5)/plant density per acre. It was coded as average ear weight * 100 on the computer card but this variable was used only in the first correlation analysis.

All observations at a few sites were deleted due to unusual conditions such as location in former barn lots or extremely poor management. Several observations from other sites were deleted because no variables were included to account for the low yields or some variable associated with the observation in that year was extremely low or high. These included those sites having prolonged flooding, very severe 2,4-D or other herbicide damage due to improper application, extremely low or high stand levels, extremely poor management, and use of white corn varieties. A few observations which had very low yields and high associated barrenness were also deleted because Henao (1976) concluded that more complex two-factor or three-factor interactions would be needed to fit these observations.

Field data

At harvest time, measurements of several variables were recorded for all observations. These included plant density, barren plants, root and stalk lodging, corn borer infestations, weed infestations, and corn rootworm damage ratings.

The corn plants in the harvested plot were recounted at harvest and the plant density (PLDEN) was calculated and listed as plants per 1/100 acre and later converted to number of plants per 1/100 ha for this study. Barren plants (BARR), but not barren tillers or suckers, were also counted and expressed as a percentage of the total plants.

At harvest time or early in the season in later years, the planting method (PLMETH) was listed and the average hill spacing (HILLSP) and average row width (ROWWID) were measured and recorded. The latter was also used to compute the harvest area. Planting method was coded 0 if drilled and 1 if hill dropped or wire checked. Hill spacing was coded 0 if drilled and to the nearest inch if hill dropped or wire checked. The average row width was coded by subtracting 28 from the average row width (nearest inch).

Root-lodged plants in the plot were counted and expressed as follows: moderately root lodged--percentage of total stalks leaning from the soil surface at an angle of 30 to 60° from vertical, and severely root lodged--percentage of stalks leaning more than 60° from vertical. For this study, the two classes of root lodging (RL1 and RL2, respectively) were later combined to give the total percentage of stalks root lodged (RL3).

The plants (stalks) broken over below the ear node at harvest (SL1) and those broken over at the ear node to the fourth node above the ear node (SL2) were counted and expressed as percentages of the total plants in the plot.

For estimates of corn borer infestations, 10 randomly-selected plants were cut off at the soil surface and sliced longitudinally (including the ear shank) and the following counts were recorded: number of cavities (feeding areas) in 10 stalks caused by first-brood corn borer (CB1), number of cavities in 10 stalks caused by second-brood corn borer (CB2ST), and number of cavities in the ear shanks of 10 plants caused by second-brood borer (CB2SH). The cavities caused by the first-brood corn borer (CB1) and the total cavities in the stalks and ear shanks caused by the second-brood corn borer (CB2) were included as variables in this study.

For estimates of weed infestations, broadleaf and grassy weeds were cut separately from an area 3 to 6 feet (0.9 to 1.8 m) wide across the width of the plot (4 or 5 rows), sacked separately, brought to Ames, hung outdoors to dry, weighed, and then calculated and listed as pounds per 0.1 acre of air-dry broadleaf (BDLF) or grassy (GRASS) weeds. In later years as experience was gained, weed weights were visually estimated if the growth was slight (up to about 200 pounds per acre). The weed variable (WEEDS) included in this study was total air-dry kg per 0.1 ha of both broadleaf and grassy weeds.

Corn rootworm damage was determined at each site from 1964 to 1970 by examination of 10 root systems sampled at harvest time as described by Henao (1976). The corn root damage rating (CRW) for the site was expressed as the sum of the ratings for the 10 root systems. For the sites harvested prior to 1964, the corn root damage ratings were estimated (Henao, 1976).

An insecticide effectiveness rating (INSEFF) for corn rootworm control was also included. It was based on the Turpin-Peters (Drs. F. T. Turpin and D. C. Peters, Department of Entomology, Iowa State University, personal communication, 1972) rating scale of 1 = no insecticide used to 9 = most effective insecticides.

Also at harvest time, the percent slope of the site (SLOPE) and the percent slope of the corn rows through the harvest area (ROWSLOPE) were measured. The slope of the site frequently varied slightly from year to year, particularly on a strongly convex slope, if the harvest area was moved a short distance for some reason. The ROWSLOPE varied with direction of planting and with adoption or dropping of contour planting. The ratio of ROWSLOPE/SLOPE was computed and coded as the computed ratio * 100. The SLRATIO variable gave the degree of contouring in the harvest area; corn rows with SLRATIO = 0 were on the contour but those with SLRATIO = 100 were up-and-down hill.

The aspect (direction of site slope on the landscape) and direction of the corn rows through the harvest area were also listed. The ASPECT and ROWDIR (from E-W to N-S) variables were coded 1 to 9 as given in Appendix Table A3.

Management data

A seven-page management questionnaire was developed to list the soil and crop management practices used by the farmer-cooperator for the year that the corn yield was checked and for the four previous years. The questionnaire was delivered and explained to the cooperator in the spring of the first year that the site was in corn; if there was a change in the operation of the farm, the same procedure was followed with the new questionnaire was mailed to him in early May so that he could record the information as the season progressed. After the site was harvested, the questionnaire was completed with the cooperator's assistance.

<u>Time trend and time period</u> To determine if a time or trend effect on yield, such as better hybrids or timeliness of operations, occurred independent of increasing levels of other management variables over the years, a trend (TREND) variable was included. It was coded 1957 = 1 to 1970 = 14. The observations over the years also were divided into two time periods (TIME), from 1957 to 1963 (coded 1) and from 1964 to 1970 (coded 2).

<u>Tillage, planting, and silking date</u> Tillage practices were described initially by several variables. The spring moldboard plowing, fall moldboard plowing, and minimum tillage were coded as follows using two columns on the computer card:

Fall moldboard plowing	0	0
Spring moldboard plowing	1	0
Not plowed (minimum tillage)	0	1

The two columns were designated SPRPLOW and MINTIL, respectively, in the correlation analysis. For regression analysis, the plowing variable (PLOW) was recoded to fall = 0, spring = 1, and none = 2.

The number of tillage operations after plowing and before planting (TILLAFT) was included. The number of times harrowed after planting (HARROW), number of times rotary hoed (HOED), and number of times cultivated (CULT) were listed initially; for regression analysis, the number of times rotary hoed and cultivated were combined into a new variable

(CULT).

The planting date (PLDATE) of each observation was coded by setting April 20 = 0. Coded dates for April, May, and June plantings thus were April date -20, May date +10, and June date +41, respectively. The 75% silking date (SLKDATE) was coded and listed as follows: the July date if silked in July and the August date +31 if silked in August.

Erosion control variables The erosion control variables listed in Appendix Table A2 were not used in this study. Manu (1979) had studied in detail the effects of these variables on corn yield using the observations from Adams, Cass, Crawford, Harrison, and Woodbury counties, the area of Iowa where erosion control practices were most commonly used. Very few sites in the other counties were near a terrace and relatively few had been contour planted. The SLRATIO variable (ratio of row slope to site slope) should give the effect of contour planting on yield in the harvest areas.

Tile line If the site center was within 200 feet of a tile line, the line was located by probing and the distance to the site was measured. In cases where the tile line was in a drainage way and had no influence on the adjacent upland site, the site was considered to be greater than 200 feet (61 m) from tile. The distance to tile (TILE) was coded as: 200 feet minus distance to tile line and converted to meters for this study and distance to tile ≥ 200 feet or 61 m thus was set = 0.

Lime and manure applications The total limestone (LIME) applied in the current year plus the three previous years was initially listed as tons per 10 acres and then later converted to metric tons per 10 ha.

The manure rate (MANURE) applied to the site area was estimated from information obtained from the farmer-cooperator, as described by Henao (1976). The rate was originally listed as tons per acre but was later transformed to metric tons per hectare.

The available nutrients per ton of manure per acre were then estimated to be 5 lb N, 5 lb P_2O_5, and 10 lb K_2O. The total nutrients per acre from manure (NMAN, PMAN, and KMAN, respectively) were listed initially and also were included in the total nutrients per acre from manure and all fertilizer sources.

Fertilizer application Information obtained from the farmer on fertilizer applications included: material or grade, rate per acre, and time and method of application. The data were listed and punched on the original computer card 2 (Appendix Table A2). The fertilizer nutrients (expressed as pounds per acre of N, P_2O_5, and K_2O) applied at each site were: N, P, and K in the hill or row fertilizer (NROW, PROW, and KROW), fall-applied N (NFALL), spring-applied, preplant N (NSPR), side-dressed N (NSD), plowed-under P and K fertilizer (PBBU and KBPU), and disked-in P and K fertilizer (PBDI and KBDI). Totals of each nutrient (expressed as pounds per acre of N, P_2O_5, and K_2O) applied in fertilizers plus those from manure (NTOTAL, PTOTAL, and KTOTAL) were also listed. The pounds of N, P_2O_5, and K_2O per acre were transformed to kg/ha of N, P, and K for the regression analyses. In addition to the original row fertilizer variables, a single row fertilizer variable was created and transferred to the new card. This ROWFERT variable was coded 0 = none and 1 = row fertilizer applied.

To determine the effects of N, P, and K fertilizers, other than row-applied nutrients, on yield, transformed variables designated NBDCT, PBDCT, and KBDCT were computed and transferred to the new data cards. NBDCT was calculated for each observation by summing the amounts of N fertilizer broadcast or banded in the fall and spring and side dressed after planting. PBDCT and KBDCT were calculated by summing the amounts of broadcast P and K fertilizers both plowed under and disked in after plowing.

A time of N application variable (NTIME) was constructed for later use to determine its effect on yield. The coded values for different times of N application were as follows:

00 = none

10 = fall application

20 = spring application before planting

30 = side dressed after planting

Because N fertilizer was applied frequently two times and occasionally three times, a weighted value for NTIME was computed as follows:

$$\text{NTIME} = \frac{(X28 * 10) + (X29 * 20) + (X30 * 30)}{X28 + X29 + X30}$$

where X28, X29, X30 = the rates of fertilizer N applied in the fall, in the spring, and side dressed after planting, respectively.

The date when N was side dressed (SDDATE) was coded and listed on the original management card, as follows:

none side dressed = 0,

in May = May date,

in June = June date + 31, and

in July = July date + 61.

The rates of side dressed N (NSD) and SDDATE were transferred to the new data cards for later use.

Because the methods of application of P and K fertilizers may have different effects on yield, the PMETH and KMETH variables were developed for this study. Their coded values were as follows:

00 = none

10 = broadcast and plowed under

20 = broadcast and disked in.

Because the P and K were applied by both methods at several sites, weighted values of PMETH and KMETH were computed as follows:

$$\text{PMETH} = \frac{(X32 * 10) + (X33 * 20)}{X32 + X33} \quad \text{and}$$

$$\text{KMETH} = \frac{(X34 * 10) + (X35 * 20)}{X34 + X35}$$

where X32, X33, X34, and X35 = rates of plowed-under P, disked-in P, plowed-under K, and disked-in K, respectively.

The transformed NTIME, PMETH, and KMETH variables were not used in this study; they were conveniently added to the new data cards for later use. Because all observations without applied N, P, and K fertilizer have to be deleted to study time or method of application, the time and method effects need to be determined in a separate series of regression models, each with a different number of observations. The effect of SDDATE on yield can be determined from the observations having side dressed N, only.

The total amounts of N, P, and K from fertilizer application (NFERT, PFERT, and KFERT) were computed and transferred to the new data card by subtracting the amounts of N, P, and K in the manure application from the total amounts of N, P, and K from both manure and fertilizer applications.

The rates of N, P, and K from manure and fertilizer applied 1, 2, and 3 years prior to the year that the corn yield was determined were listed on original data card 3 (Appendix Table A3). These residual nutrient variables were designated: NRES1, PRES1, and KRES1 (applied previous year); NRES2, PRES2, and KRES2 (applied two years previously); and NRES3, PRES3, and KRES3 (applied three years previously). The rates initially listed as pounds per acre of N, P_2O_5, and K_2O were transformed to kg/ha of N, P, and K for regression analysis.

In this study, as was done by Henao (1976), upper limits were set for the nutrient rates for all nutrient variables. These limits were 335 kg N/ha (300 lb N/acre), 98 kg P/ha (200 lb P_2O_5/acre), and 223 kg K/ha (240 lb K_2O/acre). If nutrient rates were greater than these limits (which occurred for a few observations), the rates were set equal to the upper limits. This was done to decrease the distortion in the quadratic function which forces the response curve to be symmetrical on both sides of the point where maximum yield occurs.

Crop sequence code for N and K availability   The relative effects of legumes and successive crops of corn or soybeans in the crop sequence on the N availability from the soil and residues were estimated by a cropping or N rotation coding system (NCODE). The basic coding system was 10 = 1st-year corn after 1 year of meadow, 20 = 2nd-year corn after meadow, 30 = 3rd-year corn after meadow, and 40 = 4th-year corn or more after meadow (continuous corn). The modifications of NCODE are given in Appendix Table A2 and were discussed in detail by Henao (1976).

The relative effects of cropping sequence and management of the crop on K removal and subsequent availability of K in the plow layer for the current corn crop were estimated by a cropping or K rotation coding system (KCODE), as listed in Appendix Table A2. The least K was removed by continuous corn with only the grain harvested or by diverted acres with little pasturing late in the season. Most K was removed by two or more years of meadow cut for hay or corn cut for silage.

Soil test variables Soils were sampled from each horizon at the time the profile was described and were analyzed for soil pH, buffer pH, nitrifiable N, available P, and exchangeable K by the Iowa State University Soil Testing Laboratory. A soil sample of the plow layer, 0-18 cm (0-7 inches), was also taken in the fall of each year that the plot was harvested; the soil tests from this sample were the ones used with that year's yield and other data. The plow-layer soil tests were included with the management variables in this study because they varied with the fertility and cropping management.

The soil test variables of the plow layer included the soil pH (PH1), buffer pH (PHB), nitrifiable N (STN), available P (STP1), and available or exchangeable K (STK1). PH1 was coded as (pH * 10) - 50; PHB was coded as (actual buffer pH - 6.00) * 100 with buffer pH $\geq$ 7.00

listed as 99. The STN, STP1, and STK1 were measured in pp2m; upper limits were set at 100 pp2m, 100 pp2m, and 400 pp2m, respectively. Soil tests greater than these limits were set equal to the upper limits.

The soil tests of the subsoil were included with the site and soil variables. These will be discussed later in the site and soil variables section.

All of the pH data were based on pH values for air-dry samples. Soil test N, soil test P (Bray No. 1), and soil test K (exchangeable K) values were from a field moist sample. Henao (1976) explained the laboratory methods that were used for testing the soil samples and the adjustments used to obtain comparable values because of the changes in the testing procedures in 1963 by the ISU Soil Testing Laboratory.

Transformed management data   The data on the original management cards 1, 2, and 3 were used only for a preliminary correlation analysis. Selected data from the original cards were then transferred to new management cards 1 and 2. Other data were transformed and transferred and some different variables were formed. All units in the English system were transformed into metric units. The variables transferred and those transformed and transferred from the original cards 1-3 to the new management cards 1 and 2 are listed in Appendix Table A4. The computer program used for transferring and transforming the variables is given in Appendix Table B1. The new variables developed by this program included TIME, CULT, PLOW, ROWFERT, NBDCT, NTIME, PBDCT, PMETH, KBDCT, KMETH, NFERT, PFERT, and KFERT, all of which were described previously.

Climatic Variables

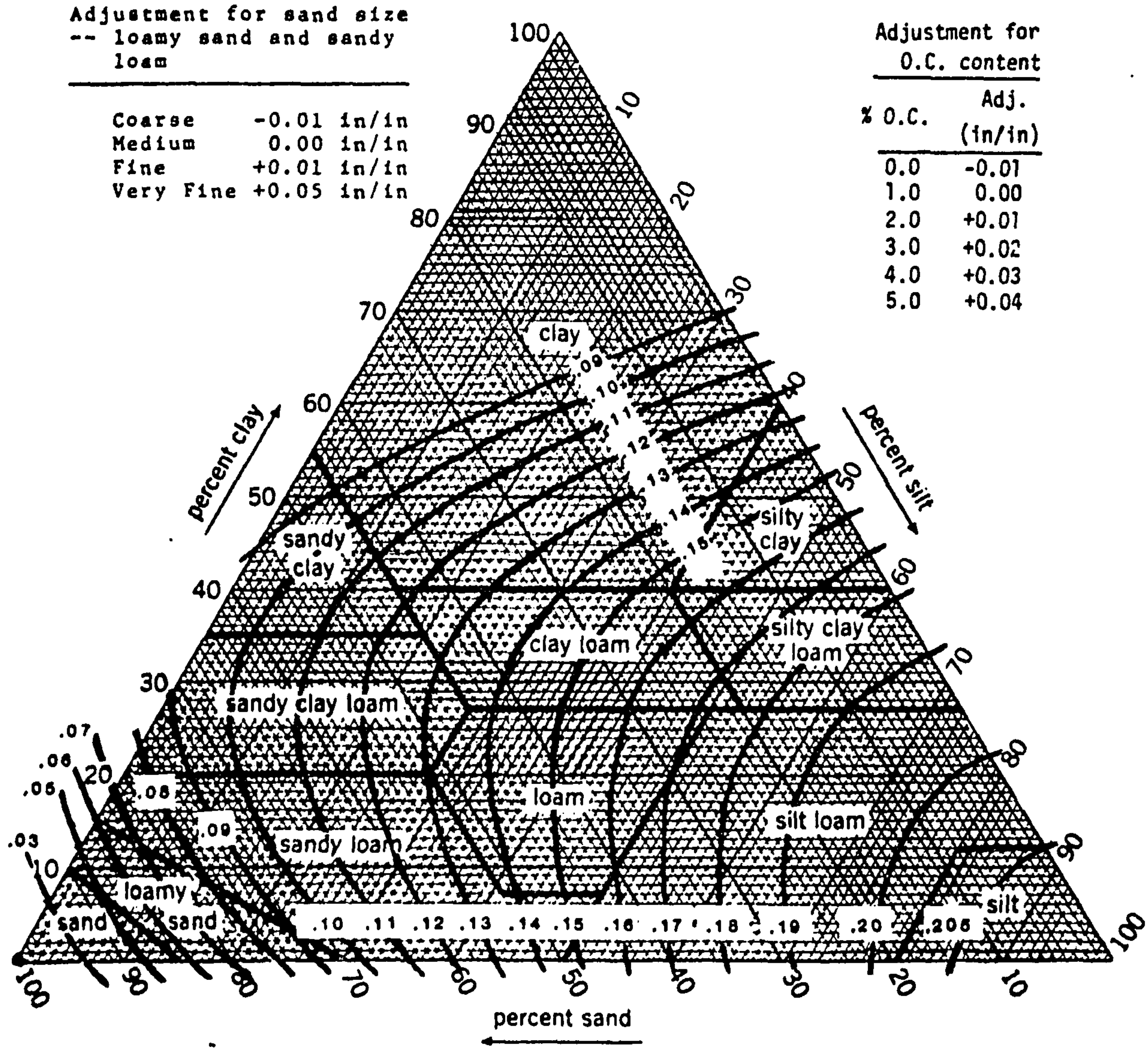
Pena-Olvera (1979) modified the weather indexes developed by Morris (1972) and Henao (1976) for his research on modeling corn yield. His major modifications were: (1) reestimation of plant available water capacity (PAWC), (2) use of a 75-day period instead of a 63-day period stress index, (3) use of the improved growth stage weighting factor (Shaw, 1974), (4) reestimation of the starting or initial plant available water (PAW) on April 15 and corrections by antecedent rainfall and runoff, and (5) use of water runoff corrections by slope, previous crop, and soil infiltration.

Reestimation of PAWC

Pena-Olvera (1979) reestimated the plant available water capacity (PAWC) for each described horizon of the profiles in the western Iowa counties that were included in his study. The PAWC values were decreased for soil horizons with more than 75% silt. The modified PAWC isolines on the textural triangle are shown in Figure 2 (Pena-Olvera, 1979). The original PAWC isolines were given by Henao (1976). The PAWC values were also reduced by the estimated percentage of gravel in each horizon or by percentage of stones in the pebble band (stone line) in many of the till-derived soils. These modifications were made in the estimated PAWC values for all profiles in the other counties included in this study.

The 75-day index

The 63-day moisture stress indexes computed by Henao (1976) summed the daily indexes from six weeks before to three weeks after the 75%



Adjustment for sand size -- loamy sand and sandy loam

Coarse	-0.01 in/in
Medium	0.00 in/in
Fine	+0.01 in/in
Very Fine	+0.05 in/in

Adjustment for O.C. content

% O.C.	Adj. (in/in)
0.0	-0.01
1.0	0.00
2.0	+0.01
3.0	+0.02
4.0	+0.03
5.0	+0.04

Figure 2. Estimated relationship between plant available water capacity (PAWC) and soil texture components (rev. 1-11-78, Dumenil and Fenton)

silking date. Pena-Olvera (1979) modified the program to extend the length of the period to 75 days (from 6 weeks before to 33 days after the silking date). The 75-day moisture stress index then was computed for all observations in the other counties used in this study.

Growth stage weighting factor

Pena-Olvera (1979) used the growth stage weighting factors developed by Shaw (1974) to replace those used by Henao (1976) in the computer program to compute the moisture stress indexes. These new weighting factors were given by Pena-Olvera (1979). These factors were expected to improve the moisture stress index because of the extra weight given to stress occurring at or near silking time, the period in which the corn plant is most sensitive to stress. They were used in the computation of the revised climatic indexes for this study.

Reestimation of starting PAW

Morris (1972) and Henao (1976) estimated the starting plant available water (PAW) from the statewide network of soil moisture measurements. For each site-year, an estimated PAW was listed for each of 5 one-foot increments, using primarily the data from Shaw et al. (1972). In the moisture program, the PAW of each one-foot increment was divided equally between the two six-inch layers in the corresponding depth increment. Each six-inch PAW value if larger than PAWC was then reduced to the layer PAWC.

Morris (1972) used the same estimated PAW for all sites within the county in a given year for corn following corn and soybeans and a different PAW for corn following meadow. These were estimated from the nearest soil moisture measurement site of the statewide network. Henao (1976) used the same values.

In the seven western counties, Pena-Olvera (1979) made and tested the following modifications of the PAW: (1) a more careful estimation of PAW from the original data from the statewide soil moisture network by using interpolated PAW values for each site if PAW values from two or more nearby soil moisture sites were available, (2) a correction of the estimated PAW at each site for antecedent rainfall at the site, and (3) a correction of the antecedent rainfall at each site for runoff. He found that the first modification of PAW increased the R^2 of the yield prediction equation, but that the second and third modifications only very slightly increased and decreased, respectively, the R^2-values. Therefore, only the first modification of PAW, corresponding to the DV3 and EM33 weather indexes tested by Pena-Olvera (1979), were used in this study.

For the rest of the observations from the counties in central and eastern Iowa included in this study, the PAW values for each of the 5 one-foot increments were carefully reestimated using the original data from the soil moisture statewide network. If two or more network stations were nearby, interpolated values for each site weighted by distance from the network stations were used. Since free water (high water table) was observed at several of the network stations, the PAW was set equal to the PAWC of the network site before obtaining interpolated values. This was done because most of the sites in the county would not be affected similarly and most of the free water would drain out of the five-foot profile before plant usage of water from the deeper root zone later in the growing season. If PAW data were not available for corn following meadow from the nearby network sites, data from other network sites were used to determine the relative PAW difference between corn after corn and corn after meadow. The PAW values at the network stations, which were determined at various dates from about April 1 to 25, were then adjusted to PAW values on April 15, the starting date of the soil moisture program. The rainfall gains and evaporation losses occurring between April 15 and date of sampling at the network site or sites were used for these estimates.

Runoff adjustments

The weather indexes derived from the soil moisture program used by Morris (1972) and Henao (1976) included a simple runoff correction based on amount of rainfall occurring at each date. Pena-Olvera (1979) then tested three other runoff adjustments to get the effective infiltrated moisture from the rainfall at each site. These adjustments considered (1) the slope of the site, (2) infiltration rate, and (3) the previous crop. Because he obtained no improvement in the R^2 of the yield prediction equation from these adjustments, they were not used in this study.

Soil moisture program

The corrected PAWC values were punched on Card 07 for the soil parameters used for computing the weather indexes (Henao, 1976). Card 07 along with Cards 06 and 03 (years each site was in corn) were used in the computer program for deriving the data punched on Cards 12-15, some of the input cards for the soil moisture program. The reestimated PAW values at the starting date were then punched on Card 10. This card along with Cards 1-8 (rainfall data), Cards 1-4 (pan evaporation data), and Cards 12-15, described before, were the necessary input cards for the soil moisture program to derive the weather indexes. Henao (1976) described the data listed on the cards and Morris (1972) described the program.

The soil moisture program used to derive the indexes for this study included some of the modifications used by Pena-Olvera (1979), as described previously. The modifications were made on the input cards and only DV3 and EM33 were punched on the output Card 53. For this study, these indexes were given the symbols DV (soil moisture stress index) and EXMO (excess moisture index). DV and EXMO were then transferred to the new computer card 2 for the multiple regression analyses of corn yield on selected variables.

Basically, the soil moisture program combines soil and atmospheric conditions into a single model which estimates the daily crop moisture status. The soil moisture percentages were used with the daily pan evaporation values to determine the relative transpiration ratio as presented by Morris (1972). The relative transpiration ratio used was obtained by using the greater of the PAW/PAWC percentage for the root zone or the PAW/PAWC percentage for the surface foot of the profile (Morris, 1972; Henao, 1976).

The moisture stress index was computed using the sum of the relative transpiration ratios for each day of the index period, which, for this study, was from 6 weeks before silking to 33 days after silking as computed by Pena-Olvera (1979). This index was weighted by energy (daily pan evaporation) and crop growth stage, as developed by Shaw (1974) and modified by Pena-Olvera (1979).

The excess moisture indexes were computed from the soil moisture program by finding the fraction of the root zone in which the layer airspace was estimated to be less than 15.0% by volume. The daily excess moisture values were summed over a 46-day period from 3 days to 49 days after planting. The excess moisture indexes were weighted by crop growth stage and energy, using the procedure developed by Morris (1972) and modified by Henao (1976).

Site and Soil Variables

Soil scientists of the Soil Conservation Service and some Agronomy Department personnel located the sites, described the soil profiles by horizons to a depth of 102 to 152 cm (40 to 60 inches), and collected soil samples by horizons for analyses. Characteristics recorded at the time the site was located and described included: horizon differentiation and boundary description; texture, color, structure, mottlings, consistence, and pH of each horizon; parent material; drainage class; biosequence; slope, configuration and aspect; erosion class; miscellaneous features of the profile; and soil unit number and soil type (Henao, 1976).

A total of 712 profiles were described in the 15 counties; 4 to 10 horizons were sampled from each profile. All observations from several of the sites were deleted by Henao (1976) and Pena-Olvera (1979). All data from several more sites were deleted in this study. The sites were deleted because of high fertility throughout the soil profile because of location in or below former feed or barn lots, abnormal characteristics of the profile or of the soil series, such as muck and shallow to bedrock units, which would require additional variables to describe them adequately, apparent errors in the original location of the site, and continued very low management levels used by the farmer. A total of 34 sites were deleted, as shown in Table 2. Data from 678 sites and 2657

Table 2. Original number and final number of sites included in this study in each of the 15 counties

County	Number of sites		
	Original	Deleted	Final
Adams	32	4	28
Bremer	36	1	35
Cass	49	3	46
Clay	46	2	44
Crawford	60	3	57
Fayette	58	3	55
Hamilton	48	2	46
Harrison	53	1	52
Howard	39	3	36
Keokuk	52	2	50
Linn	51	2	49
Lyon	49	1	48
Muscatine	35	0	35
Wayne	39	5	34
Woodbury	64	1	63
Total	712	34	678

observations (site-years) were included in the regression analyses.

Minor corrections in the values of several of the variables were made after reexamining the profile descriptions and the soil tests of the subsoil horizons for the research studies of Manu (1979), Pena-Olvera (1979), Salih (1979), and Ghaffarzadeh (1979). These corrections were made for erosion class, thickness of A horizon, slope configuration, minimum pH in the profile, depths to minimum pH, maximum clay, and top of the calcareous horizon, pH and soil test P of the 76-107 cm (30-42 in.) layer, soil test K of the 30-61 cm (12-24 in.) layer, and plant available water capacity. The parent material coding was revised along with the depth to a soil characteristic associated with the parent material group.

All original data for the site and soil variables except plant available water capacity, site slope, and site aspect were punched on computer card 05 by Henao (1976). The corrections for the variables and the revised parent material coding were made on the original data listing sheets. From these, card 05 was repunched. The revised listing and coding of the data for repunched card 05 are given in Appendix Table A5.

The next step was to transfer or transform and transfer variables on repunched card 05 to the new data card 05. Most were transferred directly, others were transformed into metric units before transferring, others were used to create new variables which were then transferred to new card 05, and some variables which had no significance on corn yield or were very highly correlated with others (Henao, 1976) were not transferred. The listing of the transformed and transferred variables from repunched to new soil variable card 05 is given in Appendix Table A6. The computer program for this operation is given in Appendix Table B2.

The new soil variable card 05 was then reproduced as card 51 for each site and year of observation. The year identification (last two digits) was added in columns 5 and 6 and locations of all other variables on new card 05 were shifted two columns on card 51.

The site and soil variables were described in detail by Henao (1976). The variables used in this study will be described briefly in the following sections; only the changes will be described in detail.

Location

The geographical location of the site within the state was determined by using two variables. For the S-N direction, the legal township number (TWP) was used which varied from TWP67 at the southern edge of Iowa to TWP100 at the northern edge of the state (TWP100, however, was listed as TWP99). The TWP variable was coded later by subtracting 65 from each value. For the E-W direction, the legal range number (RANGE) was used which was coded R1E (almost to the eastern edge of Iowa) = 0, R1W = 1, and up to R48W (western edge of Iowa) = 48.

The location of the site on the landscape was designated by two dummy variables with entries of 0 or 1 to identify upland and footslope, stream terrace, and bottomland positions. These variables were not used in this study.

Slope, configuration, and aspect

Three variables were included to describe the surface characteristics of the site area. The slope (SLOPE) of the site area, measured with an Abney level or a Clinometer, was listed as the percent slope. The slope for each year that the site was harvested was listed on Management Card 03 (Appendix Table A3).

The slope configuration (SLCONF) of the site area was coded as follows: 1 = strongly convex, 2 = convex, 3 = convex to straight, 4 = straight (flat), 5 = straight to concave, and 6 = concave.

The aspect (ASPECT) of the site (direction toward which the slope at the site faced) was coded as shown in Appendix Table A3. Henao (1976), however, showed that ASPECT had no significant effect on corn yield; it was not included in this study.

Erosion class and thickness of A horizon

The erosion class (EROS) was as determined from the profile description and was coded as follows: 0 = deposition or none (> 30 cm or 12 in. of A horizon); 1 = slight (18-30 cm or 7-12 in. of A horizon); 2 = moderate (8-18 cm or 3-7 in. of A horizon with some mixing of B horizon); and 3 = severe (< 8 cm or 3 in. of A horizon remaining). The 0 and 1 codes are different from those used by Henao (1976).

The thickness of the A horizon (THAHOR) which included the A1 + A2 (if present) + A3 horizons was recorded as inches and then transformed to cm. If THAHOR was greater than 99 cm (39 in.), it was transferred to card 51 as 99. Both EROS and THAHOR were based on the initial profile description; at some of the sites, however, erosion may have been severe enough in 10-13 years to have changed the erosion class, if the classification had been borderline initially, and the thickness of the A horizon.

Organic carbon

The percentage of organic carbon (% OC) in each described soil horizon to a depth of 51-76 cm (20-30 in.) was determined for 108 of the original 712 soil profiles included in the project. The data from these profiles together with available data from various other sources were used to regress the % OC in each described horizon on the Munsell color components (hue, value, and chroma) of moist soil, horizon depth, and location, site, and soil variables (L. C. Dumenil, Agronomy Department, Iowa State University, unpublished data, 1975). The % OC values for each horizon of all profiles used in this study were then estimated from two derived multiple regression equations, one for the plow-layer horizons (0-18 cm or 0-7 in. layers) and the other for subsurface horizons. These equations were given in Henao (1976).

Two variables from the estimated % OC distributions were used by Henao (1976); these were % OC of the 0-18 cm (0-7 in.) layer (OC1) and % OC of the 18-51 cm (7-20 in.) layer (OC2). For this study, the weighted average of OC1 and OC2 was computed (Appendix Table A6) and designated as the OC variable. The estimated % OC value of each horizon was also used along with the textural components to estimate the plant available water capacity (PAWC) of each horizon in the profile.

Natural internal drainage

The natural internal drainage class of each of the profiles was estimated from the drainage class assigned to the modal Iowa soil types by Fenton et al. (1971) and by the Soil Conservation Service, USDA (1972) and adjusted for many of the profiles that deviated from the modal soil type (Henao, 1976). The drainage class was coded for inclusion in the regression analyses as follows:

10 = excessive	60 = somewhat poor to poor
20 = excessive to well	70 = poor
30 = well	80 = poor to very poor
40 = moderately well	90 = very poor
50 = somewhat poor	

Many profiles appeared to fit between the above classes; for these, coded values midway between classes were assigned, such as 35 and 55, for example.

Soil permeability

Estimation of soil permeability (PERM) classes was based on those listed for modal Iowa soil types in Fenton et al. (1971) and Soil Conservation Service, USDA (1972). The estimated classes were adjusted to get more uniformity statewide and to give some range in the class within soil types having considerable textural variation. The coding of permeability class in relation to maximum clay in the subsoil and the adjustments for other soil variables were explained in detail by Henao (1976). The permeability class coding varied from 00 = very rapid to 90 = very slow (Appendix Table A5).

The most impervious subsurface layer was estimated for each soil profile and used in the program for calculating the weather indexes. It was the designated six-inch layer through which water movement was assumed to be the slowest. Selection of this layer in each profile was based on several factors (Henao, 1976). The most impervious subsurface layer was coded from 02 = 15-30 cm (6-12 in.) layer to 10 = 137-152 cm (54-60 in.) layer. Layer 1 (plow layer) was not listed as the most impervious layer although it may have been in a few soils.

Soil texture

Mechanical analyses were run on less than 10% of the profiles or on selected horizons of some of the profiles. For all others, the percentage clay (< 0.002 mm) and percentage sand (> 0.05 mm) fractions of each horizon of each profile were estimated by Dr. T. E. Fenton, Agronomy Department. These estimates were based on the texture of each horizon estimated by the one who described the soil profile and on many previous mechanical analyses of the textural components from the same or similar soil types. The thickness and estimated % sand and % clay values of each genetic horizon were listed and punched on Computer Card 06 (Henao, 1976). These data were part of the soil parameter data used to calculate the weather indexes. Several variables involving the clay content of the soil profile were listed. These were the % clay in the plow layer (CPL), maximum % clay (CMAX) in the subsoil below the plow layer, average % clay (CAV) in the profile from 0-152 cm (0-60 in.) and the depth (cm) to the midpoint of the subsoil horizon or horizons having the maximum % clay (DCMAX).

Another variable related to the maximum % clay in the subsoil was the subsoil group rating for crop growth (SUBGRP). Fenton et al. (1971)

had used this index based on maximum % clay, permeability, and soil plasticity to rate all soils as having subsoils favorable, moderately unfavorable, or very unfavorable for crop growth. For inclusion in regression analysis, SUBGRP was coded from 0 = very favorable to 6 = very unfavorable (Appendix Table A5) based on the maximum % clay in the subsoil and three parent material groupings (Henao, 1976).

Biosequence

To include the effect of native vegetation on soil properties and corn yield in this study, the following codes were used for the biosequence (BIO) variable:

1 = soil developed under forest vegetation
2 = forest-transition intergrade
3 = soil developed under forest and prairie vegetation (transition)
4 = transition-prairie intergrade
5 = soil developed under prairie vegetation.

The classification of each of the soils into one of the biosequence classes was based on the soil profile description.

Bulk density

Bulk density values were estimated for each horizon of each profile and listed on Card 07 (Henao, 1976). These were used to calculate the weather indexes. For yield regression, the estimated bulk densities of the 38-76 cm (15-30 in.) layer and 76-102 cm (30-40 in.) layer were listed (Appendix Table A5). For this study, only the bulk density (BD) of the 76-102 cm layer was used.

Henao (1976) explained in detail how the bulk densities were estimated for all horizons of all soils. For these estimates, bulk density distributions with depth were plotted for most major soil series; these were later presented by Dumenil (1978).

Structure

The subsoil structure (STRUCT) of the B horizon or comparable depth in an A-C profile was included by Henao (1976). The coding, based on strength of the structural units, is listed in Appendix Table A5. This variable was not included in this study.

Parent materials

The classification of the soil parent materials of the sites was revised for this study. The parent materials were identified by dummy variables (0 or 1 entries) on repunched soil variable card 05, as follows:

Parent material	Column no.					
	52	53	54	55	56	57
1. Deep loess (> 127 cm or 50 in.)	0	0	0	0	0	0
2. Loess 51-127 cm (20-50 in.) thick over till or paleosol	1	0	0	0	0	0
3. Till	0	1	0	0	0	0
4. Paleosol	0	0	1	0	0	0
5. Sand (< 127 cm or 50 in. to loamy sand, sand, or gravel)	0	0	0	1	0	0
6. Colluvium in loess areas	0	0	0	0	1	0
7. Alluvium (all except those < 127 cm to sand)	0	0	0	0	0	1

The symbols for the dummy variables for parent material groups 2 to 7 used in this study are LOESS/T, TILL, PALEO, SAND, COLLUV, and ALLUV, respectively. The distributions of profiles within each county in the soil parent material classes are given in Table 3.

The depth to, or thickness of, a parent material characteristic (DPM) in the subsoils of groups 1 to 5 were entered in the same two columns for all observations. The depth was originally coded 60 inches minus depth to the characteristic, with ≥ 60 inches set equal to 0; each was later transformed to cm, coded 152 cm - depth in cm. The following characteristics were listed:

1. Depth to deoxidized loess in the deep loess parent material,
2. Depth to till or paleosol in the shallow loess units with 51-127 cm (20-50 in.) of loess,
3. Thickness of the silty overburden or reworked material over till in till and lacustrine mapping units; this varied from 0 to 140 cm (55 in.),
4. Thickness of overburden or loess over paleosol in paleosol mapping units; this varied from 0-76 cm (30 in.), and
5. Depth to loamy sand, sand, or gravel in units on all landscape positions (upland, terrace, and bottomland); this was restricted to profiles in which depth to sand was less than 127 cm (50 in.).

The depth to, or thickness of, each of the characteristics was transformed and transferred from the repunched card 05 to the new card 05 (Appendix Table A6). These variables with the symbols of DDEOX, DLOESS/T, DTILL, DPALEO, and DSAND for parent material groups 1 to 5, respectively, were not used in this study. The effect on yield of the depth to a characteristic in the parent material only can be determined

Table 3. Number of profiles within counties with each of parent material classifications

County	Deep loess		Loess over till	Till	Paleosol	Sand	Colluvium	Alluvium	
	Not deox.	Deox.[a]						Terrace	Bottomland
Adams	6	11	1	3	4	-	-	1	2
Cass	12	14	2	3	7	-	3	3	2
Crawford	38	4	-	3	-	-	6	-	6
Harrison	19	5	-	-	-	2	8	-	18
Lyon	33	3	6	-	-	2	-	2	2
Woodbury	35	1	2	-	-	2	3	-	20
Clay	2	8	8	16	-	6	-	1	3
Hamilton	-	-	-	45	-	-	1	-	-
Wayne	1	15	2	4	10	-	-	-	2
Bremer	-	-	1	27	-	7	-	-	-
Fayette	14	-	-	32	-	6	-	1	2
Howard	-	-	-	29	-	5	-	2	-
Linn	7	2	9	15	-	12	1	1	2
Keokuk	10	23	2	1	4	-	1	3	6
Muscatine	15	4	2	-	-	8	-	1	5
Totals	192	90	35	178	25	51	22	15	70

[a]Deox. = deoxidized loess.

by analysis of the observations within the single parent material group.

Soil test variables of the subsoil

The soil tests of the subsoil were included with the site and soil variables and were assumed to have remained constant for the duration of the study. The ones originally listed by Henao (1976) are shown in Appendix Table A5.

The variables related to the pH distribution included in this study were the minimum pH (PHMIN) in the subsoil and pH of the 76-107 cm (30-42 in.) layer (PH2) in the profile. Both were coded as (pH*10) -45, i.e., pH 4.5 was listed as 0. Other pH related variables included the depth to the midpoint of the minimum pH layer (DPHMIN) which was transformed to cm. Another one was the depth to the top of the carbonate or calcareous horizon (DCAL) which was determined from the profile description. This was coded: 60 inches minus depth with ≥ 60 inches = 0; later it was transformed to 152 cm minus depth with ≥ 152 cm = 0.

Only the soil test P level of the 76-107 cm (30-42 in.) layer (STP2) in pp2m was used in this study. This layer has the maximum soil test P level in the profile in most soils with a sigmoid P distribution with depth, but has slightly less soil test P than the layers nearer the surface in the soils with a decreasing P distribution (Salih, 1979). The soil test K level of the 30-61 cm (12-24 in.) layer (STK2) was used in this study; it was highly correlated with the soil test K in the deeper layers (Ghaffarzadeh, 1979).

Plant available water capacity

Many of the plant available water capacity (PAWC) values for the horizons in each profile were reestimated as described in the climatic variables section. The original estimates of PAWC values were described in detail by Henao (1976). The method of estimating PAWC from the modified isolines superimposed on the textural triangle and the adjustments for organic carbon and size of sand fraction are shown in Figure 2, discussed previously.

The PAWC for each horizon were punched on the computer card 07 (Henao, 1976) for use in deriving the weather indexes. Total PAWC value for the 152 cm (60 in.) root zone was calculated for each profile by the computer program and punched on card 12, columns 68-72. These PAWC values were then transferred to new data card 03 for this study.

Statistical Procedures

Multiple regression analysis was used to provide estimates of the effects of many variables on corn yield. Models were selected on the basis of the significance of the regression coefficients, no variables correlated greater than $r = \pm\ 0.60$ to minimize distortion of the regression coefficients in the model, and selection of the one of a pair or group of correlated variables that gave the higher or highest R^2.

Four steps or stages were used to select the final yield prediction model. First, the most important management variables in the presence of climatic variables were selected in a series of quadratic models, the MODEL A series. Second, soil variables were added to the selected variates from the final model of the MODEL A series and the most important soil variables were selected in a series of quadratic models, the MODEL B series. Third, many of the interactions between the selected variables from the final MODEL B series were added and tested in a series of models (MODELS C to H series) to select the most significant interaction variates to include in the final model. Fourth, the most significant linear, quadratic, and interaction variates were selected for the final prediction model of corn yield on management, climatic, and soil variables in the MODEL J series.

<u>The multiple regression model</u>

All computations to determine the effects of many variables[1] on corn yield were carried out with respect to the model:

$$Y_i = B_0 + B_1X_{1i} + B_2X_{2i} + \dots + B_pX_{pi} + \varepsilon_i \quad , \tag{1}$$

which is the usual multiple regression model having Y as the dependent variate, the explanatory factors X_1, X_2, ... X_p which are assumed to be independent, ε_i which is the error term because the postulated independent variates do not completely explain Y_i, and the parameters B_0, B_1, ... B_p which are the population regression coefficients. The usual assumptions in the regression analyses were made except that it was recognized that the X's in these data were intercorrelated to a varying degree. Pena-Olvera (1979) studied the intercorrelations among the soil variables used in this study and presented an extensive discussion of

[1]The term "variable" will refer to a factor under study whose effect in the regression model and analysis may be a function of one or more variates or terms (X_i). "Variate" will refer to a single term included in the multiple regression model and analysis.

the effects of intercorrelation on the results of multiple regression analysis.

Model selection

In the initial steps of statistical analysis in the MODEL A and B series, the correlations between variables included in the models were examined. Correlated variables were tested initially in different alternate models. Then, stepwise, backward elimination of nonsignificant variates was then applied.

The criteria for retention of given variates in the model were: (1) after the t-test for significance was applied to each of the partial regression coefficients, only those were retained in the equation whose probability was less than $\alpha = 0.15$ initially and less than $\alpha = 0.10$ in final stages of model selection except that the linear variate was retained regardless of its significance if its squared or any interaction variate was significant at $\alpha = 0.10$; (2) no variables were to be included with correlations > ±0.60; and (3) after comparing correlated variables in alternate models, the one of the pair that gave the higher R^2-value, although only slightly higher in some cases, was retained in subsequent models and the others were deleted.

The fitting of the multiple regression equations was done by using the computer program, the Helarctos II (Kennedy, 1971). This program is particularly well-adapted to fit models by the least squares method because of its built-in facility to create different functions out of the columns of the X matrix containing a maximum of 100 independent variates. All the regression statistics from the regression analysis were printed in the computer output as options.

Interpretation of the quadratic functions

The effect of any variable (X_i) on corn yield (YIELD) in the quadratic model can be computed by taking the partial derivative of YIELD with respect to the X_i variable, which gives,

$$dYIELD/dX_i = b_i + 2b_{ii}X_i \quad , \tag{2}$$

where b_i and b_{ii} = the regression coefficients of the linear and squared variates, respectively. The partial derivative in equation 2 gives the slope of the curve, or the change in YIELD per unit change in X_i, at any level of X_i with all other variables held constant.

The value of X_i that gives the maximum or minimum YIELD is obtained by setting the partial derivative in equation 2 equal to 0 and solving for X_i,

$$b_i + 2b_{ii}X_i = 0 \quad \text{and}$$

$$X_i = -b_i/2b_{ii} \quad . \tag{3}$$

If the sign of b_i is positive and that of b_{ii} is negative in equation 2, the quadratic function has a maximum value of YIELD for some positive level of X_i; if the signs of the coefficients are reversed, the function has a minimum YIELD for some positive level of X_i. If signs of both coefficients are negative, the computed maximum YIELD is at a negative X_i and outside the relevant range; in the relevant range, YIELD decreases at an increasing rate (higher negative slope) as X_i

increases. If signs of both are positive, the computed minimum is at a negative X_i and outside of the relevant range; in the relevant range, YIELD increases at an increasing rate (higher positive slope) as X_i increases.

<u>Interpretation of linear and quadratic functions with interactions</u>

The effects of a variable which has a linear or curvilinear effect on YIELD modified by linear*linear interactions can be determined by taking the partial derivative of the YIELD regression equation with respect to the variable. For a variable, X_1, having a linear function plus interactions with two other variables, X_2 and X_3, in the YIELD regression equation, the terms in the regression equation giving the effect of X_1 on YIELD are b_1X_1, $b_2X_1X_2$, and $b_3X_1X_3$, where b_1 to b_3 are the partial regression coefficients for X_1 and the interactions of X_1X_2 and X_1X_3, respectively.

The partial derivative of YIELD with respect to X_i is,

$$dYIELD/dX_1 = b_1 + b_2X_2 + b_3X_3 \quad . \tag{4}$$

Equation 4 gives the slope (change in YIELD per unit change of X_1) of the linear response of YIELD to X_1 at any level of X_2 and X_3. Thus, the presence of interactions alters the slope of the linear response of YIELD to X_1. To get the slope of YIELD on X_1 at fixed levels of X_2 and X_3, the means or any other selected values of X_2 and X_3 are substituted into equation 4; the products of b_2X_2 and b_3X_3 are then added to b_1 to give the slope of the linear function of YIELD on X_1.

If the X_1 variable has a quadratic (curvilinear) function plus interactions with two other variables (X_2 and X_3) in the YIELD regression equation, the relevant terms in the regression equation are b_1X_1, $b_{11}X_1^2$, $b_2X_1X_2$, and $b_3X_1X_3$, where b_1, b_{11}, b_2, and b_3 are the partial regression coefficients for X_1, X_1^2, X_1X_2, and X_1X_3, respectively. The partial derivative then is,

$$dYIELD/dX_1 = b_1 + 2b_{11}X_1 + b_2X_2 + b_3X_3 \quad . \qquad (5)$$

Equation 5 gives the slope (change in YIELD per unit change in X_1) of the YIELD response curve at any level of X_1, X_2, and X_3.

To get the simplified partial derivative of YIELD on X_1 at fixed levels of X_2 and X_3, the means or any other selected values of X_2 and X_3 are substituted into equation 5; the products of b_2X_2 and b_3X_3 are then added to b_1 to give the simplified derivative of YIELD on X_1 at fixed levels of X_2 and X_3. This equation (which is the same as equation 2) can be used to compute the X_1 that gives the minimum or maximum YIELD as shown by equation 3.

Another way to determine the level of X_1 that gives the minimum or maximum YIELD from the partial derivative of YIELD with respect to X_1 is to set equation 5 equal to 0 and solve for X_1, as follows:

$$0 = b_1 + 2b_{11}X_1 + b_2X_2 + b_3X_3 \quad ,$$

$$2b_{11}X_1 = -b_1 - b_2X_2 - b_3X_3 \quad , \text{ and}$$

$$X_1 = \frac{-b_1 - b_2X_2 - b_3X_3}{2b_{11}} \quad . \qquad (6)$$

The interactions not only alter the slope of the response of YIELD on X_1 in equation 5 but also change the value of X_1 that gives the minimum or maximum YIELD in equation 6. That is, minimum or maximum YIELD will be associated with lower or higher levels of X_1 as levels of the interaction variables change. To determine X_1 at minimum or maximum YIELD, fixed values of X_2 and X_3 are substituted into equation 6, the products of b_2X_2 and b_3X_3 are added to b_1, and X_1 then is computed. As the number of interactions increases, the interpretation of the effects of variables on YIELD becomes more complex.

<u>Interpretation of variable effects on yield using changes in yield (ΔYIELD)</u>

To determine the additive (positive or negative) changes in yield or yield response due to the effect of a particular variable or variables, ΔYIELD values can be computed from the yield prediction equation easier than the absolute yield values can be computed. The intercept (b_0) and values of all other variables are set equal to zero, except for the variable or variables having interactions with the variable or variables being studied. All of the interacting variables are then set equal to selected constant values and the simplified ΔYIELD equation is derived as functions of the one, two, or more variables being studied. This procedure for two variables is shown as follows, starting with the final yield prediction equation:

$$\begin{aligned} \text{YIELD} = {} & b_0 + b_1X_1 + b_2X_2 + \ldots + b_iX_i + b_pX_p + \\ & b_{11}X_1^2 + b_{22}X_2^2 + \ldots + b_{ii}X_i^2 + b_{pp}X_p^2 + \\ & b_{12}X_1X_2 + b_{1i}X_1X_i + b_{2i}X_2X_i + b_{ip}X_iX_p \quad , \end{aligned} \tag{7}$$

where X_1 and X_2 are the variables being studied, X_i are the variables that have interactions with X_1 or X_2, and X_p are the variables that have no interactions with either X_1 or X_2. By setting the values of b_0 and the X_p variables equal to zero and the values of the X_i variables equal to their selected constants, C_i, in equation 7, the ΔYIELD equation for the effects of X_1 and X_2 becomes:

$$\Delta\text{YIELD} = (\sum b_i C_i + \sum b_{ii} C_i^{\ 2}) + (b_1 + \sum b_{1i} C_i)\ X_1 + (b_2 + \sum b_{2i} C_i) X_2 + b_{11} X_1^{\ 2} + b_{22} X_2^{\ 2} + b_{12} X_1 X_2 \quad . \qquad (8)$$

From equation 8, the values for X_2 can be set at various levels and the ΔYIELD values for increasing levels of X_1 computed. Because all computed ΔYIELD values due to the effect of the variable on ΔYIELD are relative, one of the values was set equal to 0 by subtracting its value and this constant was subtracted from all others. This was done for convenience in plotting the effects of the variables on ΔYIELD. As can be seen in equation 8, the relationships between ΔYIELD and the X_1 or X_2 variables being studied are changed to a varying degree if the constant levels of the interacting variables are changed. The change in the constant in equation 8 has no effect on the relative difference among ΔYIELD values but changes in the coefficients of the linear X_1 and X_2 variates alter the initial slopes and the X_1 and X_2 values associated with minimum or maximum ΔYIELD values.

A computer program was written for calculation of the ΔYIELD values for designated combinations of levels of a selected group of variables. The regression coefficients of the final yield prediction model were entered into the computer, the intercept and values of all variables not interacting with those studied were set equal to zero, the values of the interacting variables were set equal to constant levels, and selected levels of the variables being studied were designated. The ΔYIELD values for the designated combinations of levels of the selected group of variables were then computed and printed in the output. As explained previously, one ΔYIELD value was set equal to zero and this constant was subtracted from all others prior to plotting the ΔYIELD values.

RESULTS AND DISCUSSION

Analysis of the data for this project was started by Morris (1972) who developed and tested different moisture stress and excess moisture indexes in regressions of corn yield on climatic and selected management variables. He used data from 7 of the 15 counties included in the study.

Henao (1976) then modified the moisture stress and excess moisture indexes developed by Morris using data from all counties. He tested the weather indexes in yield regression models in the presence of selected management variables. He then concentrated on selecting the most significant soil variables affecting corn yield from all available data on soil properties.

Manu (1979), using data from upland soils in five western counties, studied the effects of soil conservation practices on corn yield. His yield regressions included soil variables, weather indexes modified by Henao, and additional management variables.

Further modifications of the climatic indexes and soil variable data were again studied by Pena-Olvera (1979) along with selected management variables in corn yield regression models. He used data from the seven counties in western Iowa. He also examined the intercorrelations among variables using several methods including latent roots and vectors of the correlation matrix. The intercorrelated variables need to be identified because correlated variables cause difficulty in the interpretation of the variable effects on yield in yield regressions (Henao, 1976; Pena-Olvera, 1979).

The major objective of this research was to select the most important management variables from all available ones that could be included in a yield regression model using data from all counties. Several of the management variables such as time and method of fertilizer application and time periods can be studied only by using part of the data. The two weather indexes, moisture stress and excess moisture, were recomputed based on the modifications by Pena-Olvera (1979). The soil variables which were found to be important by Henao (1976) were included. Some values of the soil parameters were corrected after reexamining the profile descriptions. Others, including erosion class and parent material parameters, were coded somewhat differently from the way Henao had coded them. Variables were also selected to eliminate high correlations between variables because the yield - variable relationships were of more interest than the highest precision (R^2) of the prediction equation.

The results of this study will be presented in four sections. In the first section, the most significant management variables in the presence of recomputed climatic indexes were selected using multiple regressions of corn yield on linear or quadratic functions of these variables. In the second section, the most significant soil and location variables were selected in the presence of the previously-selected management and climatic variables using linear or quadratic functions of the variables in the yield models.

The many linear by linear interactions between the management, soil, and climatic variables were tested in a series of yield regression models in the third section, using the most significant linear and squared variates tested previously as the base set of variates. In the fourth and last section, the most significant linear, quadratic, and interaction variates were selected for the final multiple regression yield model. The effects of the variables and their interactions on corn yield were discussed in detail.

Selection of Management Variables

The management variables included in this study were selected from the data collected for Project 1377 (replaced by Project 1958 in 1972 and then Project 2326 in 1978) of the Iowa Agriculture and Home Economics Experiment Station. The management variables were described in the Materials and Methods chapter. The management data were originally punched on three computer cards (Appendix Tables A1 to A3) and then were repunched on the new computer cards 1 and 2 (Appendix Table A4). Two climatic variables, DV and EXMO, which had been modified and recomputed for each observation were included in the regression modeling for selection of the management variables. A total of 2657 observations (site/years) from the 15 counties from 1957 to 1970 (Table 1) were included in the regression analyses.

Preliminary correlation analysis

Simple correlation coefficients among 73 original management variables listed on original management cards 1, 2 and 3 (Appendix Tables A1, A2, and A3) and three transformed variables were computed for preliminary examination. If correlations between variables are high enough, variable selection can be made at this stage to avoid the effects of highly-correlated variables in the regression model. Some correlated variables may be combined or grouped for later analysis. Some correlations in the preliminary analysis had little meaning, however, because the variables needed to be recoded or transformed for regression analysis.

The correlation coefficients greater than ±0.44 between the variables are shown in Table 4. The linear correlation between YIELD and

Table 4. Some simple correlations between management variables greater than r = ±0.44, preliminary correlation analysis

Between variables		r	Between variables		r
YIELD and	TREND	.36	PLMETH and	HILLSP	.94
TREND and	PLDEN	.60	NTOTAL and	NRES1	.53
	NTOTAL	.58		NRES2	.54
	PTOTAL	.45		NRES3	.49
	NFERT	.61			
	PFERT	.53	NRES1 and	PRES1	.80
				KRES1	.65
BARR and	EARWT	-.61		NRES3	.47
			PRES1 and	KRES1	.85
RL1 and	RL3	.85			
RL2 and	RL3	.80	NRES2 and	PRES2	.76
				KRES2	.60
CB2SH and	CB2ST	.81		NRES3	.45
	CB2	.88	PRES2 and	KRES2	.79
CB2ST and	CB2	.99			
			NRES3 and	PRES3	.77
GRASS and	WEEDS	.92		KRES3	.64
BDLF and	WEEDS	.46	PRES3 and	KRES3	.83

TREND (coded years) was low. However, Pena-Olvera (1979) had reported a marked quadratic effect of TREND on YIELD because the yield effects of increasing management levels, as shown by the high correlations between TREND and PLDEN (plant density) and applied nutrient variables, were offset by severe moisture stress in 1968 and 1970. Because the effect of TREND was confounded with the PLDEN, applied nutrient, and moisture stress variables, it was deleted from further analyses.

The high correlation between BARR (barren plants) and EARWT (average ear weight per stalk) was expected. The EARWT variable is a yield component (ratio of yield and plant density) and was deleted. Any factor that directly decreases yield and increases barrenness will decrease EARWT.

Two classes of root lodging were recorded, moderate lodging (RL1) and severe lodging (RL2). Because total root lodging (RL3) was so highly correlated with both RL1 and RL2 (Table 4), only RL3 was used in the regression analyses. Because second-brood corn borer in the ear shanks (CB2SH), in the stalks (CB2ST), and the total in both plant parts (CB2) were highly correlated, only CB2 was used in the regressions. There was a high correlation between amounts of total weeds (WEEDS) and grassy weeds (GRASS) but a lower correlation between WEEDS and broadleaf weeds (BDLF). Only the WEEDS variable was included in the regression analyses. Planting method (PLMETH) was very highly correlated with hill spacing of hill-dropped corn. Only PLMETH was retained for regression analysis.

The residual amounts of total nutrients from manure and fertilizer were very highly correlated within a given time after application (Table 4). Residual N effects usually occur in the first year after application, residual K effects may occur in the first year after application and possibly in the second year depending on crop removal of K, and residual P effects occur for several years after application. The NRES1, PRES1, and KRES1 variables (total N, P, and K applied the previous year), the PRES2 and KRES2 variables (total P and K applied two years previously), and PRES3 (total P applied three years previously) were retained for regression analysis. The high correlations between these variables indicate that only one residual nutrient variable per year can be retained in a regression.

Regressions of yield on quadratic functions of management and climatic variables, MODEL A series

Variables included in the yield regressions, their symbols, means, and ranges (minimum and maximum observed values) are given in Table 5. A total of 49 management variables, 2 climatic variables, and the time period variable were included. The variables are grouped in Table 5 but some miscellaneous variables were also included in some of the groups. The environmental group contained the variables measured at harvest time except INSEFF (insecticide effectiveness rating). Some of these such as insect and weed infestations reflect the use or nonuse of pesticides. The tillage and planting group contained variables relating to seedbed preparation, cultivation, and planting. SLOPE, a soil variable, was included because it was used in the SLRATIO variable, an index of contour planting. TILE was a miscellaneous variable.

The fertility management group included many variables, from which several combinations were to be tested in alternate regression models.

Table 5. Symbols, identification, means, and ranges of variables included in the yield regressions on management and climatic variables, MODEL A series

Symbol	Variable[a]	Mean	Range
YIELD	Corn yield, dependent variable, q/ha	65.1	9-117
TIME	Time period, coded 1957-63 = 1, 1964-70 = 2	1.50	1-2
	Environmental group		
BARR	Barren plants, %	4.8	0-53
RL3	Root lodged plants, moderate + severe, %	9.9	0-99
CRW	Corn root (rootworm) damage rating, coded 10 to 60	15.1	10-54
SL1	Stalk lodged plants, broken below ear node, %	4.1	0-84
CB1	First brood corn borer, cavities/10 plants	3.3	0-38
CB2	Second brood corn borer, cavities/10 plants	14.5	0-99
WEEDS	Total weeds, grassy + broadleaf, kg/0.1 ha	57.6	0-475
INSEFF	Insecticide effectiveness rating, coded 1-9	3.0	1-9
	Tillage and planting group		
PLOW	Time of plowing, coded fall = 0, spring = 1, none = 2	0.74	0-2
TILLAFT	Tillage operations after plowing, number of times	3.9	0-9
PLDATE	Planting date, coded days after April 20	24.5	0-56
PLMETH	Planting method, coded drilled = 0, hill dropped = 1	0.48	0-1
PLDEN	Plant density, no. of plants/0.01 ha	359.7	193-751
ROWWID	Row width, coded row width in cm minus 71 cm	29.0	0-48
ROWDIR	Row direction, coded 1 to 9	5.1	1-9

[a]More complete descriptions of the variables and coding used are given in Appendix Tables A1, A2, A3, or A4.

Table 5. (Continued)

Symbol	Variable	Mean	Range
CULT	Rotary hoed and cultivated, no. of times	2.9	0-7
SLKDATE	75% silking date, coded July date or Aug. date + 31	30.2	8-56
SLOPE	Slope of the site area, %	4.2	0-21
ROWSLOPE	Slope of corn rows through harvest area, %	1.7	0-13
SLRATIO	Ratio ROWSLOPE/SLOPE, coded*100	43.4	0-99
TILE	Distance to tile line, coded 61 m - distance in m	5.7	0-61
	<u>Fertility management group</u>		
LIME	Limestone in current year + 3 previous years, MT/10 ha	6.0	0-134
MANURE	Manure applied, MT/ha	4.8	0-67
ROWFERT	Row fertilizer, coded 0 = none, 1 = rowfert. applied	0.53	0-1
NROW	N applied in row fertilizer, kg N/ha	5.5	0-84
PROW	P in row fert., kg P/ha	7.9	0-47
KROW	K in row fert., kg K/ha	9.0	0-67
NBDCT	Total N fert. other than NROW, kg N/ha	56.0	0-336
PBDCT	Total P fert. other than PROW, kg P/ha	7.8	0-98
KBDCT	Total K fert. other than KROW, kg K/ha	10.1	0-223
NTOTAL	Total N from manure + fert., kg N/ha	73.6	0-336
PTOTAL	Total P from manure + fert., kg P/ha	21.0	0-98
KTOTAL	Total K from manure + fert., kg K/ha	39.0	0-223
NFERT	Total N fert., kg N/ha	61.5	0-336
PFERT	Total P fert., kg P/ha	15.7	0-98
KFERT	Total K fert., kg K/ha	19.1	0-223
NCODE	Crop sequence code for N availability, coded 8-40	23.0	8-40
KCODE	Crop sequence code for K availability, coded 0-60	17.8	0-60
NRES1	Total N (manure + fert.) applied previous year, kg N/ha	36.3	0-336
PRES1	Total P (manure + fert.) previous year, kg P/ha	11.3	0-88

Table 5. (Continued)

Symbol	Variable	Mean	Range
KRES1	Total K (manure + fert.) previous year, kg K/ha	24.4	0-223
PRES2	Total P applied 2 years previously, kg P/ha	11.8	0-88
KRES2	Total K applied 2 years previously, kg K/ha	23.3	0-223
PRES3	Total P applied 3 years previously, kg P/ha	9.4	0-88
	Soil tests of plow layer group		
PH1	Soil pH, coded (soil pH*10)-50	15.1	1-32
PHB	Buffer pH, coded (buffer pH-6.00)*100	73.0	0-99
STN	Soil test N (field moist), pp2m N	64.6	24-100
STP1	Soil test P (field moist), pp2m P	30.8	5-100
STK1	Soil test K (field moist), pp2m K	209.3	35-400
	Climatic group		
DV	Soil moisture stress index	3.81	1.1-5.2
EXMO	Excess moisture index	1.27	0-14.8

Some variables listed in Appendix Table A4 were included for future use. These included times and methods of fertilizer applications. These can be tested only in special models because only the observations receiving some rate of the nutrient can be used to test its time or method of application.

The group of soil test variables of the plow layer were included with the management variables because they reflected previous fertility management. Two climatic variables, the moisture stress index (DV) and excess moisture index (EXMO), were included in the development of all models because of their important effects on yield.

Variates included in the MODEL A series of regressions are listed in Table 6. YIELD was the dependent variable. A total of 52 independent variables were included. Quadratic functions of 47 of these variables were included; five variables (TIME, PLMETH, ROWFERT, ROWSLOPE, and ROWDIR) had only linear functions. The maximum number of independent variates which could be included in the computer program (HELARCTOS II) was 99 variates.

Correlation analysis Simple correlation coefficients between all linear variates included in the MODEL A series were determined at the same time as the initial multiple regression was computed by the HELARCTOS II program. Those greater than $r = \pm.45$ are listed in Table 7. The magnitudes of the correlation coefficients between variables were considered in model selection. Alternate models were computed to determine which variable or combination of variables could be retained to minimize correlation between variables present in the initial model and maximize

Table 6. Variates included in the regression of corn yield on quadratic functions of management and climatic variables, MODEL A series

X_i	Variate	X_i	Variate	X_i	Variate
1	YIELD[a]	35	NCODE	69	$LIME^2$
2	TIME	36	KCODE	70	$MANURE^2$
3	PLDEN	37	NRES1	71	$NROW^2$
4	BARR	38	PRES1	72	$PROW^2$
5	RL3	39	KRES1	73	$KROW^2$
6	CRW	40	PRES2	74	$NBDCT^2$
7	INSEFF	41	KRES2	75	$PBDCT^2$
8	SL1	42	PRES3	76	$KBDCT^2$
9	CB1	43	SLOPE	77	$TILE^2$
10	CB2	44	ROWSLOPE	78	$NTOTAL^2$
11	WEEDS	45	SLRATIO	79	$PTOTAL^2$
12	CULT	46	ROWDIR	80	$KTOTAL^2$
13	PLOW	47	PH1	81	$NFERT^2$
14	TILLAFT	48	PHB	82	$PFERT^2$
15	PLDATE	49	STN	83	$KFERT^2$
16	SLKDATE	50	STP1	84	$NCODE^2$
17	PLMETH	51	STK1	85	$KCODE^2$
18	ROWWID	52	DV	86	$NRES1^2$
19	LIME	53	EXMO	87	$PRES1^2$
20	MANURE	54	$PLDEN^2$	88	$KRES1^2$
21	ROWFERT	55	$BARR^2$	89	$PRES2^2$
22	NROW	56	$RL3^2$	90	$KRES2^2$
23	PROW	57	CRW^2	91	$PRES3^2$
24	KROW	58	$INSEFF^2$	92	$SLOPE^2$
25	NBDCT	59	$SL1^2$	93	$SLRATIO^2$
26	PBDCT	60	$CB1^2$	94	$PH1^2$
27	KBDCT	61	$CB2^2$	95	PHB^2
28	TILE	62	$WEEDS^2$	96	STN^2
29	NTOTAL	63	$CULT^2$	97	$STP1^2$
30	PTOTAL	64	$PLOW^2$	98	$STK1^2$
31	KTOTAL	65	$TILLAFT^2$	99	DV^2
32	NFERT	66	$PLDATE^2$	100	$EXMO^2$
33	PFERT	67	$SLKDATE^2$		
34	KFERT	68	$ROWWID^2$		

[a]YIELD is the dependent variable regressed on 52 independent variables.

Table 7. Simple correlation coefficients greater than ±0.45 between yield and management variables and between management variables, MODEL A series

Between variables		r	Between variables		r
YIELD and	PLDEN	.52	PBDCT and	KBDCT	.61
	NBDCT	.46		PTOTAL	.62
	NTOTAL	.47		NFERT	.47
	NFERT	.47		PFERT	.81
				KFERT	.49
TIME and	PLDEN	.50			
	NBDCT	.52	KBDCT and	PTOTAL	.52
	NTOTAL	.51		KTOTAL	.47
	NFERT	.53		NFERT	.47
	PFERT	.46		PFERT	.65
				KFERT	.90
PLDEN and	ROWWID	-.47			
	NBDCT	.58	NTOTAL and	PTOTAL	.69
	NTOTAL	.59		KTOTAL	.52
	PTOTAL	.48		NFERT	.92
	NFERT	.60		PFERT	.59
	PFERT	.54		KFERT	.47
	KFERT	.53		NRES1	.53
PLDATE and	SLKDATE	.62	PTOTAL and	KTOTAL	.79
MANURE and	PTOTAL	.55		NFERT	.50
	KTOTAL	.82		PFERT	.79
ROWFERT and	NROW	.79		KFERT	.59
	PROW	.86	KTOTAL and	KFERT	.55
	KROW	.70			
			NFERT and	PFERT	.65
NROW and	PROW	.83		KFERT	.50
	KROW	.58		NRES1	.51
PROW and	KROW	.76	PFERT and	KFERT	.72
	PFERT	.52			
	KFERT	.51	NRES1 and	PRES1	.80
KROW and	KFERT	.55		KRES1	.65
			PRES1 and	KRES1	.85
NBDCT and	PBDCT	.49	PRES2 and	KRES2	.79
	KBDCT	.47			
	NTOTAL	.92	NCODE and	KCODE	-.52
	PTOTAL	.48	SLOPE and	ROWSLOPE	.50
	NFERT	.99	ROWSLOPE and	SLRATIO	.49
	PFERT	.63	PH1 and	PHB	.87
	KFERT	.47	STP1 and	STK1	.46
	NRES1	.50			

the precision or R^2 of the prediction equation.

YIELD was most highly correlated with PLDEN, NBDCT, NTOTAL, and NFERT (Table 7). The PLDEN and any one of the N fertility variables thus were expected to have dominant effects on YIELD. The intercorrelations among these N fertility and other variables will be discussed later in this section.

The TIME variable, used to divide the observations into two time periods, was highly correlated with PLDEN and some of the fertility variables (Table 7) just as TREND was correlated with the same variables (Table 4). With the increasing use of fertilizer during the time of this study, plant density levels were also increased, as shown by the high correlations between PLDEN and the fertility variables. Increasing plant density was followed by the use of narrower row widths; PLDEN and ROWWID were negatively correlated (r = -0.47).

The SLKDATE variable was highly correlated with PLDATE (r = 0.62). Some of the effects of SLKDATE can be accounted for by the PLDATE variable. The PH1 and PHB variables were also highly correlated (r = 0.87). Only one of these can be included in the model; they were tested in alternate models to select the better one. Other variables with moderately high correlations included NCODE and KCODE, ROWSLOPE with both SLOPE and SLRATIO, and STP1 and STK1.

The fertility variables were highly intercorrelated with one another, as shown by the correlation coefficients among and within different fertility groups in Table 8. The respective nutrients in the NTOTAL, PTOTAL, and KTOTAL variables (total nutrients from manure and

Table 8. Simple correlation coefficients greater than ±0.45 between variables within the fertility group

Variables	NROW	PROW	KROW	N-BDCT	P-BDCT	K-BDCT	N-FERT	P-FERT	K-FERT	N-TOTAL	P-TOTAL	K-TOTAL
ROWFERT	.79	.86	.70	--	--	--	--	--	--	--	--	--
NROW	--	.83	.58	--	--	--	--	--	--	--	--	--
PROW		--	.76	--	--	--	--	.52	.51	--	--	--
KROW			--	--	--	--	--	--	.55	--	--	--
NBDCT				--	.49	.47	.99	.63	.47	.92	.48	--
PBDCT					--	.61	.47	.81	.49	--	.62	--
KBDCT						--	.47	.65	.90	--	.52	.47
NFERT							--	.65	.50	.92	.50	--
PFERT								--	.72	.59	.79	--
KFERT									--	.47	.59	.55
NTOTAL										--	.69	.52
PTOTAL											--	.79
KTOTAL												--

fertilizers), the NFERT, PFERT, and KFERT variables (total nutrients from fertilizers), and the NBDCT, PBDCT, and KBDCT variables (nutrients from all fertilizers except row fertilizer) were very highly intercorrelated. Correlations were highest between the N variables and somewhat less between the P and K variables. Only one of these sets can be used in the regression model. If the NTOTAL set is used, no other nutrient variables are required; if the NFERT set is used, the MANURE variable is required; but if the NBDCT set is used, the MANURE and one or more of the row fertilizer variables are required to account for all nutrients applied.

Other correlations considered were those between nutrients within each of the NTOTAL, NFERT, and NBDCT sets of variables (Table 8). These correlations were lowest within the NBDCT set. The correlations between N and P and P and K in the other sets were high enough to cause distortion of the regression coefficients and limit the determination of the yield - nutrient relationships. Even the correlation between PBDCT and KBDCT ($r = 0.61$) was high enough to cause distortion of the regression coefficients if both were included in the regression. The high correlations occurred within the NTOTAL, NFERT, and NBDCT sets because a constant ratio between N, P, and K was used to estimate nutrients in manure applications and because many farmers used similar N-P-K ratios in their row fertilizer and total broadcast P and K plus preplant or sidedressed N fertilizers.

The dummy ROWFERT variable (0 = none or 1 = row fertilizer applied) was very highly correlated with the NROW, PROW, and KROW variables (rates of N, P, and K applied in the row) (Table 8). The correlations between NROW, PROW, and KROW were also high as explained in the previous paragraph. If one of these were to be used, the PROW would be preferable because its high correlations with both NROW and KROW will explain most of their effects on yield.

The high correlations between the residual nutrient variables were discussed in the preliminary correlation analysis section. They occurred because similar ratios of total N, P, and K were applied to corn by many farmers.

All of the high correlations between variables were considered in the selection of the most important management variables for predicting yield. The series of alternate models to test the effects of the correlated variables will be described in the next section.

Model selection The model selection steps for the MODEL A series are listed in Table 9. The initial regression of YIELD (MODEL A-1) on all variates listed in Table 6 had an $R^2 = 0.772$. The deletion of the BARR variable reduced the R^2 to 0.651. Thus, about 12% of the yield variation was accounted for by the BARR variable in the model. The reduction in R^2 was less than that reported by Henao (1976). This may be because the additional management variables in these models explained part of the yield variation due to barren stalks. As reported in the Literature Review chapter, the barren stalk variable should be deleted to study the effects of the management variables on yield.

Deletion of the SLKDATE variable, highly correlated with PLDATE ($r = 0.62$), reduced the R^2 to 0.613 after the BARR variable was deleted

Table 9. Model selection steps, MODEL A series

Model no.	No. of X variates	Model selection steps	R^2
A- 1	99	Complete model, all variates listed in Table 6	.7717
2	97	Deleted BARR variable (linear and squared variates) from MODEL A-1	.6508
3	97	Deleted SLKDATE variable from MODEL A-1	.7466
4	95	Deleted SLKDATE and BARR variables from MODEL A-1	.6130
5	74	Tested NTOTAL, PTOTAL and KTOTAL variables; deleted MANURE, ROWFERT, NROW, PROW, KROW, NBDCT, PBDCT, KBDCT, NFERT, PFERT, KFERT from MODEL A-4	.6904
6	76	Tested MANURE, NFERT, PFERT and KFERT variables; deleted ROWFERT, NROW, PROW, KROW, NBDCT, PBDCT, KBDCT, NTOTAL, PTOTAL, and KTOTAL variables from MODEL A-4	.6904
7	82	Tested MANURE, NROW, PROW, KROW, NBDCT, PBDCT, and KBDCT variables; deleted ROWFERT, NTOTAL, PTOTAL, KTOTAL, NFERT, PFERT, and KFERT variables from MODEL A-4; MODEL A-7 had highest R^2	.6099
8	77	Tested ROWFERT variable; deleted NROW, PROW, and KROW from and added ROWFERT to MODEL A-7	.6098
9	78	Tested NROW; deleted PROW and KROW from MODEL A-7	.6097
10	78	Tested PROW; deleted NROW and KROW from MODEL A-7	.6095
11	78	Tested KROW; deleted NROW and PROW from MODEL A-7	.6094
12	80	Tested PHB; deleted PH1 from MODEL A-7	.6064
13	80	Tested PH1; deleted PHB from MODEL A-7; MODEL A-13 had higher R^2 than MODEL A-12	.6088

Table 9. (Continued)

Model no.	No. of X variates	Model selection steps	R^2
14	76	Tested NRES1; deleted PRES1 and KRES1 from MODEL A-13	.6083
15	76	Tested PRES1; deleted NRES1 and KRES1 from MODEL A-13	.6075
16	76	Tested KRES1; deleted NRES1 and PRES1 from MODEL A-13; MODEL A-14 had highest R^2	.6077
17	74	Tested PRES2; deleted KRES2 from MODEL A-14	.6081
18	74	Tested KRES2; deleted PRES2 from MODEL A-14	.6079
19	72	Tested NCODE; deleted KCODE from MODEL A-17	.6072
20	72	Tested KCODE; deleted NCODE from MODEL A-17	.6002
21	72	Tested ROWSLOPE; deleted SLRATIO from MODEL A-17	.6078
22	73	Tested SLRATIO; deleted ROWSLOPE from MODEL A-17	.6075
23	70	Tested NROW; deleted PROW and KROW from MODEL A-17	.6079
24	70	Tested PROW; deleted NROW and KROW from MODEL A-17	.6077
25	70	Tested KROW; deleted NROW and PROW from MODEL A-17	.6075
26	72	Tested PBDCT; deleted KBDCT from MODEL A-17	.6078
27	72	Tested KBDCT; deleted PBDCT from MODEL A-17	.6079
28 to 31	66 to 56	Deleted ns $WEED^2$, $PLOW^2$, $ROWWID^2$, $STK1^2$, $SL1^2$, $TILE^2$, $EXMO^2$, CRW^2, $KCODE^2$, PLOW, $INSEFF^2$, $LIME^2$, $TILLAFT^2$, and $SLRATIO^2$ stepwise from MODEL A-24	.6076 to .6060

Table 9. (Continued)

Model no.	No. of X variates	Model selection steps	R^2
32 to 34	51 to 45	Deleted ns TIME, ROWWID, ROWDIR, $NRES1^2$, $PRES2^2$, INSEFF, LIME, PRES2, SLRATIO, $CULT^2$, and $PRESS^2$ from MODEL A-31	.6051 to .6042
35	42	Deleted ns KBDCT, PRES3, and $KBDCT^2$, from MODEL A-34; this was the final model	.6035

(MODEL A-4, Table 9). These two variables were then deleted from all subsequent models because they appeared to be yield components and to confound other variable effects on yield (Henao, 1976).

Highly correlated variables within the fertility group were next tested alternately in MODELS A-5 to A-7 (Table 9). MODEL A-7 gave the highest R^2 of 0.610. This showed that the MANURE, row-applied fertilizer (NROW, PROW, and KROW), and fertilizer applied other than row (NBDCT, PBDCT, and KBDCT) were slightly better than the other combinations. The variables in the NBDCT set also had less intercorrelation than the variables in the NFERT and NTOTAL sets. Therefore, MODEL A-7 was selected as the base model for the next model selection steps.

The row fertilizer variables were next tested alternately in MODELS A-8 to A-11 (Table 9). The dummy ROWFERT variable gave a slightly higher R^2 than the others. Inclusion of one of the NROW, PROW, or KROW variables instead of ROWFERT was preferred in order to estimate the curvilinear effect of nutrient rates on YIELD. Additional tests of the row fertilizer variables were made later.

The relative importance of PH1 and PHB on YIELD was tested in MODELS A-12 and A-13. PH1 gave a higher R^2 than PHB, as was found by Henao (1976). The PHB variable was then deleted from further models.

In MODELS A-14 to A-18, the first-year residual effects of NRES1, PRES1, and KRES1 and second-year effects of PRES2 and KRES2 were tested (Table 9). The NRES1 and PRES2 variables were retained and the others were deleted.

In the next series of model selection steps, the correlated variables of NCODE and KCODE ($r = -.52$), ROWSLOPE and SLRATIO ($r = .50$), PBDCT and KBDCT ($r = .61$), and again the highly correlated NROW, PROW, and KROW variables were evaluated in MODELS A-19 to A-27 (Table 9). Because the NCODE and KCODE variables, the slope-related variables, and the PBDCT and KBDCT fertilizer variables are useful variables to retain and may be involved in logical interactions, only the NROW and KROW variables were deleted after testing in this series. NROW gave a slightly higher R^2 than the others, but PROW was retained because previous research has shown that the PROW effect is markedly influenced by the PBDCT variable (Casanova, 1979). Most interactions involving row fertilizer can be more logically explained with PROW than with any of the others in the model.

At this stage of the testing, no variables correlated greater than $r = 0.61$ were present in the model. For the selection of the final model, nonsignificant variates were then deleted stepwise from MODEL A-24 (Table 9). MODEL A-35 was selected as the final model; the R^2 was reduced from 0.608 in MODEL A-24 to 0.6035 in MODEL A-35. No variables were correlated >±0.45 in the final model except PLDEN and NBDCT (r = 0.58), NBDCT and PBDCT (r = 0.49), NBDCT and NRES1 (r = 0.50), SLOPE and ROWSLOPE (r = 0.50), NCODE and KCODE (r = -0.52), and STP1 and STK1 (r = 0.46). The final MODEL A-35 had 42 variates including 27 linear and 15 squared terms.

The relative importance of different groups of variables for explaining yield variation in final MODEL A-35 is shown in Table 10 by the reduction of R^2 as each group of variables was alternately deleted from MODEL A-35. The two weather indexes, DV primarily, had the largest effect on yield; deletion of these decreased the R^2 by about 0.12. The five tillage and planting variables, primarily PLDEN, had the next largest effect; their deletion decreased the R^2 by about 0.07. Deletion of the four soil test variables decreased the R^2 by about 0.05, followed by decreases of 0.04, 0.03, and 0.02 in the R^2 as the six environmental, five fertility, and two crop rotation variables, respectively, were deleted alternately from MODEL A-35. From this backward elimination procedure, the relative importance of the different groups of variables on yield was: climatic > tillage and planting > soil test > environmental > fertility > crop rotation.

Interpretation of effects of the variables on yield The regression statistics of the final quadratic model of yield on management and climatic variables, MODEL A-35, are given in Table 11. Its analysis of variance is given in Appendix Table A7. All of the regression coefficients for the quadratic variates were significant at either the 5%

Table 10. Effects of deletion of variable groups from final MODEL A-35

Model no.	No. of X variates	Variables deleted from MODEL A-35	R^2
A-35	42	--	.6035
37	39	Weather indexes of DV and EXMO	.4808
42	35	Tillage and planting variables of PLDEN, CULT, TILLAFT, PLDATE, and PLMETH	.5347
41	40	PLDEN variable	.5507
38	35	Soil test variables of PH1, STN, STP1 and STK1	.5532
43	33	Environmental variables of RL3, CRW, SL1, CB1, CB2, and WEEDS	.5645
40	33	Fertility variables of MANURE, PROW, NBDCT, PBDCT, and NRES1	.5724
39	39	Crop rotation variables of NCODE and KCODE	.5865

or 1% level except those for PROW and PBDCT. These variates were retained in the model, however, to test their effects in later models.

The effects of the variables on yield in MODEL A-35 will be discussed briefly in the following subsections although the interpretations given in Table 11 explain the general yield response patterns. The use of partial derivatives and computation of the yield responses will be explained and illustrated in the first subsection. In quadratic models, the variable effects are determined at average or constant levels of all other variables. If interactions between variables are important, the

Table 11. Regression statistics of the selected final quadratic model of yield on management and climatic variables, MODEL A-35[a]

Variable[b]	b_i Linear	b_i Quadratic	Interpretation of the effect of the variable on yield[c]
			Environmental group
RL3	0.0365	-0.000859*	YMAX at 21% root lodged
CRW	-0.324**	--	Y decr. 0.32 q/ha per unit from 10 to 54
SL1	-0.221**	--	Y decr. 0.22 q/ha per 1% increase in stalk lodging
CB1	0.597**	-0.0313**	YMAX at 9.5 cavities/10 plants (moderate CB1)
CB2	0.161**	-0.00163**	YMAX at 49 cavities/10 plants (mod.-severe CB2)
WEEDS	-0.0305**	--	Y decr. 0.03 q/ha per kg weeds/0.1 ha (from 0 to 475)
			Tillage and planting group
TILLAFT	0.262++	--	Y incr. 0.26 q/ha per tillage operation after plowing
PLMETH	-1.12*	--	Y was 1.1 q/ha less in hilled than in drilled corn
CULT	-0.639**	--	Y decr. 0.64 q/ha for each time hoed or cultivated
PLDATE	0.0418	-0.00520*	YMAX at 4 (planted April 24)
PLDEN	0.179**	-0.000148**	YMAX at 605 or 60,500 plants/ha (24,500 stalks/A)
SLOPE	0.509**	-0.0376**	YMAX at 6.8% slope
ROWSLOPE	-0.303*	--	Y decr. 0.3 q/ha for each 1% increase in row slope
TILE	0.0602**	--	Y incr. 0.06 q/ha per 1 m that site was closer to tile line from 61 to 0 meters

[a]Intercept = -74.7; R^2 = 0.603; no. of obs. = 2657; and no. of variates = 42.

[b]Means, ranges, and units of the variables are given in Table 5.

[c]YMAX = maximum yield, YMIN = minimum yield, and Y = yield.

**,*,++,+Significant at the 1%, 5%, 10%, and 15% levels, respectively, in this and all subsequent tables.

Table 11. (Continued)

Variable[b]	b_i Linear	Quadratic	Interpretation of the effect of the variable on yield[c]
			Fertility group
MANURE	0.177**	-0.00421*	YMAX occurred at 21.0 MT/ha (9.4 T/A)
PROW	0.0716	-0.00169	YMAX at 21.2 kg P/ha (43.3 lb P_2O_5/A)
NBDCT	0.0953**	-0.000164**	YMAX at 290 kg N/ha (259 lb N/A)
PBDCT	0.0160	-0.000408	YMAX at 19.6 kg P/ha (40 lb P_2O_5/A)
NRES1	0.0135*	--	Y increased 0.014 q/ha per kg N/ha in previous year
NCODE	-0.634**	0.00852**	YMIN at 37 (4th-year corn)
KCODE	0.0430*	--	Y increased 0.04 q/ha per unit increase in KCODE from 0 to 60
			Soil tests of plow layer
PH1	1.272**	-0.0330**	YMAX at PH1 = 19.2 (pH of 6.9)
STN	0.705**	-0.00433*	YMAX at 81 pp2m (medium-high soil test N)
STP1	0.457**	-0.00389**	YMAX at 59 pp2m (high soil test P)
STK1	0.0122**	--	Y incr. 0.012 q/ha per increase of 1 pp2m K
			Climatic indexes
DV	21.72**	-1.539**	YMAX at 7.1 (no stress, highest obs. index = 5.2)
EXMO	-1.414**	--	Y decr. 1.4 q/ha per unit increase in EXMO from 0 to 15

average response to one variable is less meaningful than the responses of the variable at various levels of the interacting variables. Thus, interpretation of variable effects in a quadratic regression model is similar to interpretation of average yield responses to individual fertilizer nutrients in a factorial experiment in which marked interactions occur.

RL3 The RL3 (total root lodging) variable had a curvilinear effect on yield (Table 11). The first partial derivative of YIELD in the regression equation with respect to RL3 is:

$$\begin{aligned} dYIELD/dRL3 &= 0.0365 - 2(0.000859)\ RL3 \\ &= 0.0365 - 0.001718\ RL3 \quad . \end{aligned}$$

To find the slope of the YIELD response function at any level of RL3, the RL3 value is substituted into the partial derivative. For example, the slope of the YIELD function at RL3 = 10 is:

$$\begin{aligned} slope &= 0.0365 - 0.001718\ (10) \\ &= 0.0193 \quad . \end{aligned}$$

This slope shows that the change in YIELD at the point on the response curve where RL3 = 10 was 0.019 q per unit (percent) change of RL3, with all other variables held constant.

At the maximum point on the response curve, the slope will equal 0, and the level of RL3 at this point is calculated by setting the partial derivative = 0 and solving for RL3, as follows:

$$0 = 0.0365 - 0.001718\ RL3, \quad \text{and}$$

$$RL3 = 0.0365/0.001718 = 21.25 \quad .$$

The maximum yield (YMAX) thus occurred at RL3 = 21%. The YMAX was expected to occur at 0% root lodging. Because the linear coefficient of RL3 was not significantly different from 0, the 95% confidence interval included negative values of the coefficient. If both linear and quadratic coefficients were negative, YIELD would decrease at an increasing rate as RL3 increased.

The change in yield (ΔYIELD) between two levels of RL3 can be computed from the partial derivative by multiplying the average slope between the points by the change in RL3 levels (ΔRL3). The average slope of the yield response curve between RL3 = 0 (slope = 0.0365) and RL3 = 21.2 (at YMAX, slope = 0) was (0.0365 + 0)/2 = 0.01825. The ΔYIELD thus was 0.01825*21.2 = 0.39 q/ha, a very slight difference.

As root lodging increased above 21%, YIELD decreased at an increasing rate. At RL3 = 100, the slope of the yield response curve was -0.135. The ΔYIELD as RL3 increased from 21 to 100% was (0 - 0.1353)/2*79 = -5.3 q/ha (8.4 bu/acre). Because the corn yields were obtained by hand harvesting all corn from the plots, the estimated yield losses from root lodging in this study do not include the machine harvest losses. These losses vary with the degree and direction of root lodging and other factors.

The yield responses (ΔYIELD) to increasing levels of RL3 are shown in Figure 3A. The ΔYIELD values between RL3 levels can be computed from the partial derivative as shown previously. A simpler method for quadratic models is to use the coefficients of the linear and quadratic (squared) variates (Table 11); thus, $\Delta YIELD = 0.0365\ RL3 - 0.000859\ RL3^2$.

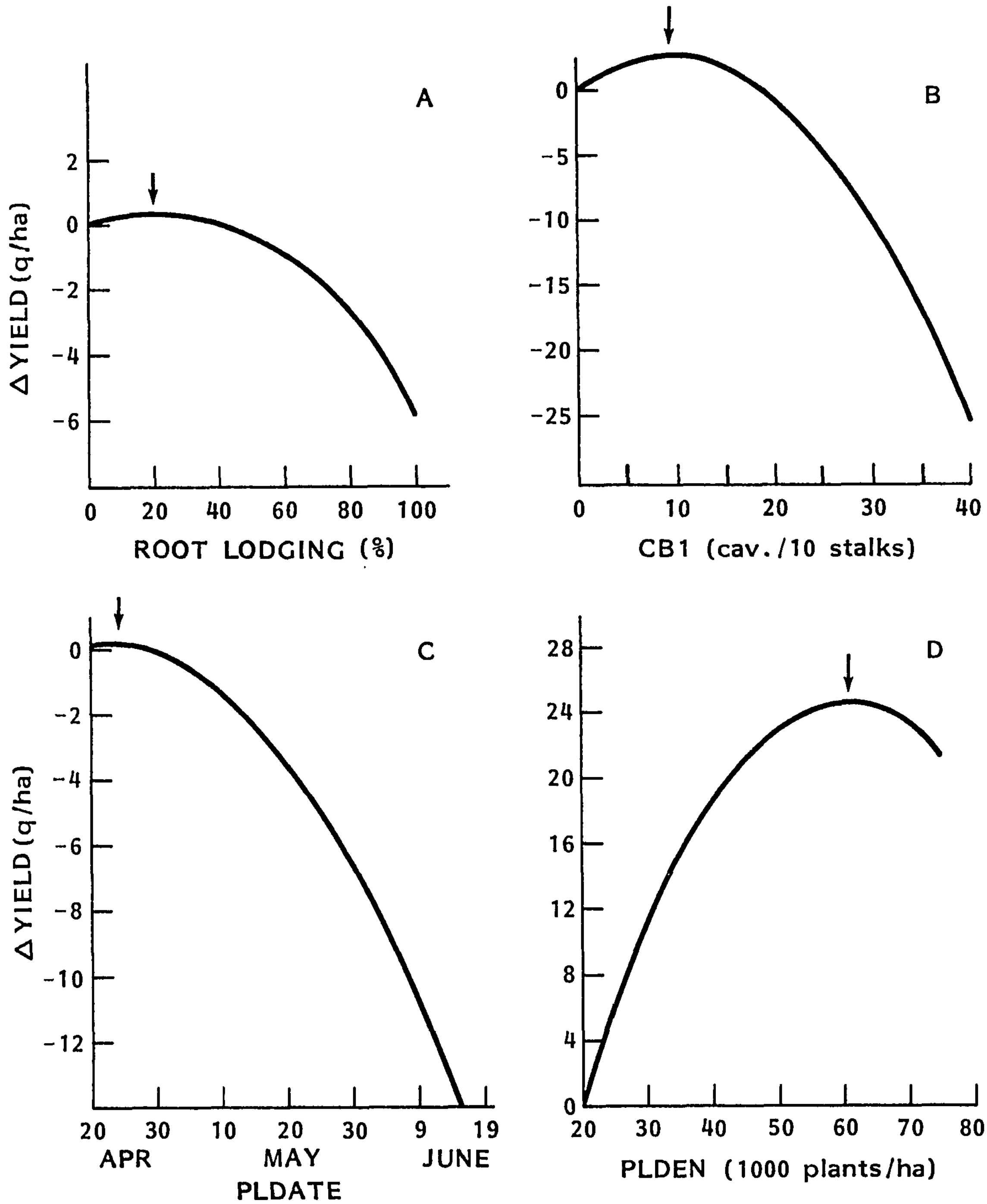


Figure 3. Change in yield (ΔYIELD) with: (A) root lodging (RL3), (B) first brood corn borer (CB1), (C) planting date (PLDATE), and (D) plant density (PLDEN)

Selected RL3 values from 0 to 100 (the observed range of values) were substituted into the ΔYIELD equation to get the ΔYIELD values.

The ΔYIELD values are relative changes. The ΔYIELD values of some variables (to be discussed later), which had minimum values greater than 0, were adjusted by subtracting the ΔYIELD value of the minimum observed value from all ΔYIELD values. Thus, ΔYIELD at the minimum observed value of the variable was set equal to 0 and all other ΔYIELD values were changes relative to this 0 value. If the minimum value of the variable was 0, as in the case of RL3, the ΔYIELD values were computed directly.

<u>CRW</u> The regression coefficient of the CRW variate (Table 11) gives the slope of the linear yield response on corn root damage rating (rootworm infestation). Corn yield decreased linearly 0.324 q/ha per unit increase of coded CRW; from 10 (no damage) to 54 (maximum observed rating), the estimated yield decrease was 14.2 q/ha (22.6 bu/acre). Turpin et al. (1972) reported that yield decreased at an increasing rate as CRW increased. Both Henao (1976) and Pena-Olvera (1979) reported a curvilinear effect of CRW on yield in their preliminary models but only a negative, linear effect in their final models. Increased machine harvest losses of corn due to increased CRW damage and associated root lodging were not accounted for in this study.

<u>SL1</u> The percentage of stalk lodged plants broken below the ear node averaged about 4% and varied from 0 to 84% (Table 5). The SL1 variable significantly decreased corn yield 0.22 q/ha per 1% increase in stalk lodging. Manu (1979) reported a similar negative effect of stalk lodging on yield. Increased machine harvest losses from increased stalk

lodging were not accounted for.

CB1 First-brood corn borer infestation averaged 3.3 cavities/10 plants and ranged from 0 to 38 cavities/10 plants. From data in Table 11, dYIELD/dCB1 = 0.597 - 0.0626 CB1; YMAX thus occurred at CB1 = 9.5 cavities/10 plants. This was the same as was reported by Henao (1976).

The curvilinear effect of CB1 on corn yield is shown in Figure 3B. The ΔYIELD from CB1 = 0 to 9.5 (level that gave YMAX) was 2.8 q/ha (4.5 bu/acre). As CB1 increased above 9.5, corn yield decreased at an increasing rate; from CB1 = 9.5 to 38, the ΔYIELD was -25.4 q/ha (40 bu/acre).

A YMAX at CB1 = 0 was expected but it occurred at a moderate infestation. The corn borer moths lay their eggs on the earliest-planted, fastest-growing, heaviest-fertilized corn and larval survival is higher with these conditions, as discussed in the Literature Review chapter. The positive effect of slight to moderate infestations of first-brood corn borer on corn yield thus may be confounded with the better yield-increasing management practices in this study. Pena-Olvera (1979) and Manu (1979) also reported similar effects of CB1 on yield in the data from western Iowa where corn borer infestations were higher than in other areas of the state.

CB2 From data in Table 11, the partial derivative of YIELD with respect to CB2 (second-brood corn borer infestation) = 0.161 - 0.00326 CB2. The YMAX occurred at 49 cavities/10 stalks, a moderate-severe infestation. The ΔYIELD from CB2 = 0 to 49 was 3.9 q/ha; from

CB2 = 49 to 99, it was -4.0 q/ha (-6.4 bu/acre). Henao (1976), Manu (1979), and Pena-Olvera (1979) found similar effects of CB2 on corn yield. As was discussed in the CB1 subsection, the positive effect of slight to moderate-severe levels of CB2 on yield appears to be confounded with the high level of management that attracts the egg-laying moths and increases larval survival. Both CB1 and CB2 increase machine harvest losses which were not accounted for in this study.

WEEDS Weed populations decreased corn yield linearly 0.03 q/ha per kg weeds/0.1 ha. The yield decrease from the highest observed weed infestation of 475 kg/0.1 ha (4750 kg/ha or 4240 lb/acre) was 14.5 q/ha (23 bu/acre).

TILLAFT Number of tillage operations after plowing had a positive, linear effect on yield of 0.26 q/ha (0.4 bu/acre per tillage operation from 0 to 9 times. The effect of TILLAFT was significant at only the 10% level. Also, the average yield response per tillage operation was less than the cost of the operation.

PLMETH This variable compared the planting methods of hill-dropped and drilled corn. The drilled corn had 1.1 q/ha more yield than the hill-dropped corn. Almost all corn in Iowa is now drilled.

CULT Corn yield was decreased 0.64 q/ha for each time the field was rotary hoed and cultivated (Table 11). The average number of times hoed and cultivated during the study period was 2.9 times, and the maximum was 7 times (Table 5). Cultivation reduces the weed population if done at an early stage which could improve the yield. Cultivations at later stages may cause considerable root damage and stalk breakage.

The data from this model showed that up to seven cultivations caused highly significant yield reductions up to 4.5 q/ha (7 bu/acre).

PLDATE From the data in Table 11, the dYIELD/dPLDATE = 0.0418 - 0.0104 PLDATE. YMAX occurred at 4 (decoded, April 24). This was earlier than the planting dates associated with YMAX that Henao (1976) and Manu (1979) reported. The corn yield response to PLDATE is shown in Figure 3C. Although most researchers have reported that corn yield decreased if planted after May 10 to 15, the yield decrease by delaying planting from April 24 to May 10 was only 1.3 q/ha (2.1 bu/acre). Yield then decreased at an increasing rate if planted after May 10.

PLDEN Plant density had a curvilinear effect on yield in MODEL A-35, as shown in Figure 3D. This type of yield response to PLDEN was expected. The dYIELD/dPLDEN = 0.179 - 0.000296 PLDEN and YMAX occurred at coded PLDEN = 605 (60,500 plants/ha). The ΔYIELD was 24.3 q/ha (39 bu/acre) as PLDEN increased from 20,000 to 60,500 plants/ha (8,100 to 24,500 plants/acre). The average PLDEN was 36,000 plants/ha (14,800 plants/acre).

SLOPE The SLOPE variable had a curvilinear effect on yield (Table 11 and Figure 4A). YMAX occurred at SLOPE = 7%. Since SLOPE is a soil variable, its effects on corn yield will be discussed with the soil variables in the next model series.

ROWSLOPE The slope of the rows through the site area gave the degree that the corn was planted on the contour at the slightly sloping to steeply sloping sites. If corn was planted on the contour, the

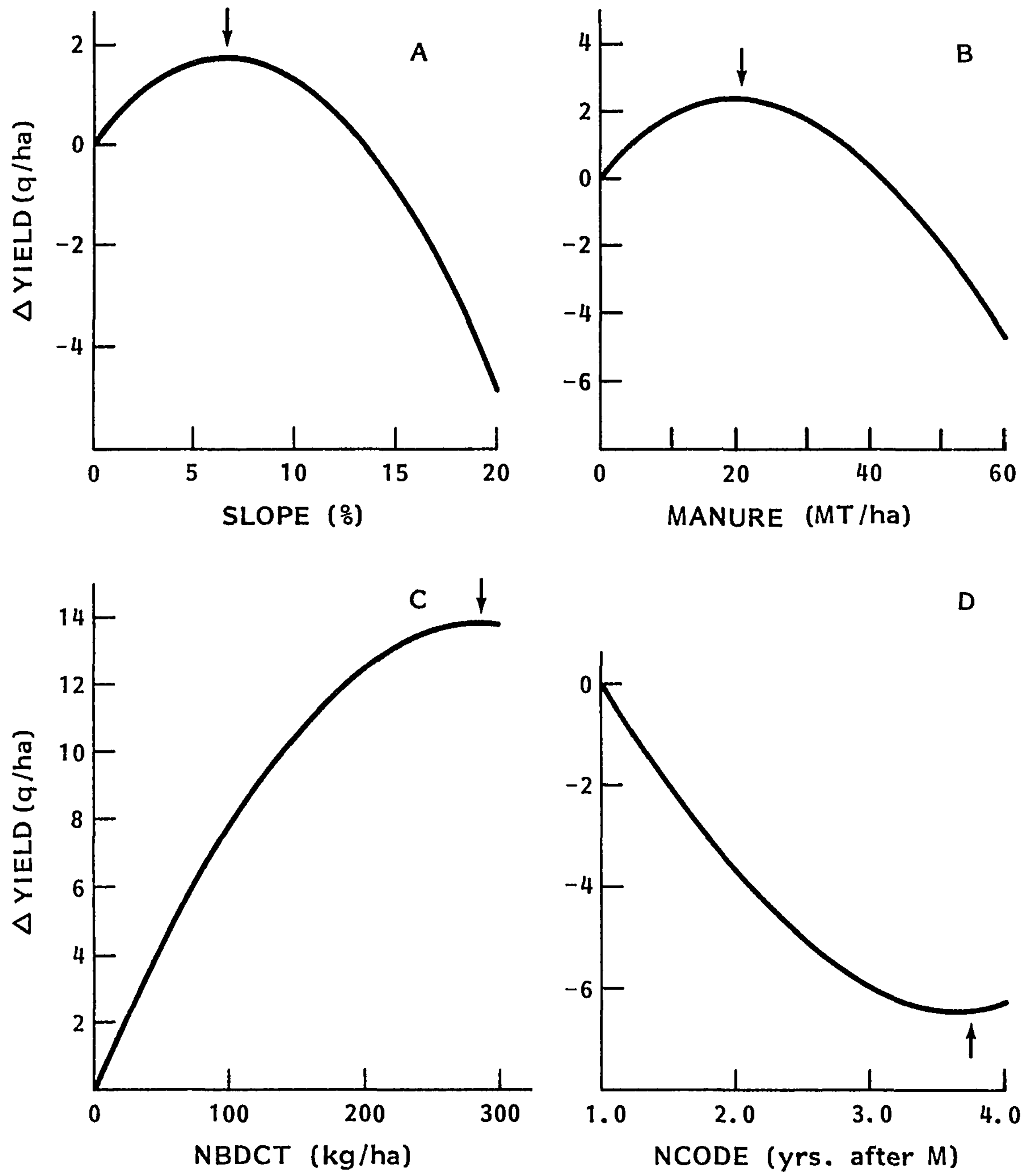


Figure 4. Change in yield (ΔYIELD) with: (A) site slope (SLOPE), (B) manure (MANURE), (C) N fertilizer (NBDCT), and (D) position in the crop rotation (NCODE)

ROWSLOPE = 0; if the ROWSLOPE = SLOPE (site slope), the corn was planted up-and-down hill. At the level to nearly level sites up to 2-3% slope, ROWSLOPE has little effect on corn yield.

ROWSLOPE had a negative, linear effect on YIELD of 0.3 q/ha (0.48 bu/acre) per 1% increase in ROWSLOPE from 0 to the maximum observed value of 13%. The yield decrease from 0 to 13% row slope was about 4 q/ha (6 bu/acre). The effects of ROWSLOPE and SLOPE may be somewhat distorted in the regression because they were correlated (r = 0.50). The SLOPE*ROWSLOPE interaction should be of more value in the regression model.

<u>TILE</u> In MODEL A-35 (Table 11), TILE (coded distance to tile) had a positive, linear effect on corn yield. The yield increased 0.06 q/ha per 1 m that the site was closer to a tile line, within the range from 61 to 0 m. This yield response agrees with that reported by Henao (1976).

<u>MANURE</u> The dYIELD/dMANURE (Table 11) = 0.177 - 0.00842 MANURE; YMAX occurred at 21 MT/ha (9.4 T/acre). Yield responses to manure rates are shown in Figure 4B. The ΔYIELD from 0 to 21 MT/ha was only 1.9 kg/ha (3.0 bu/acre). The responses to manure rates were less than expected; the yield decreases from the higher rates also were unexpected. The manure rate at YMAX contained about 53, 23, and 87 kg/ha of N, P and K, respectively. Because the manure effects on yield are those at average levels of the applied fertilizers, interactions between MANURE and fertilizer variables should characterize the yield response to MANURE better.

PROW The regression coefficients for PROW were not significant at the 10% level in the final model (Table 11). This variable was retained, however, because its effects on yield were expected to be dominated by interactions with other fertility variables. The dYIELD/dPROW = 0.0716 -0.00338 PROW; YMAX was obtained with 21.2 kg P/ha applied along the row. The ΔYIELD from this rate was only about 0.8 q/ha (1.2 bu/acre). Because of the high correlation between PROW and both NROW and KROW (Table 8), this variable also includes most of their effects on corn yield.

NBDCT The yield response to NBDCT (all N fertilizer except row-applied N) in MODEL A-35 (Table 11) is shown in Figure 4C. The dYIELD/dNBDCT = 0.0953 - 0.000328 NBDCT: YMAX occurred at 290 kg N/ha which appears high for the average PLDEN of 36,000 plants/ha. Average rate of NBDCT was 56 kg N/ha; the highest rate was 336 kg N/ha (Table 5). The ΔYIELD from 0 to 290 kg N/ha was 13.8 q/ha (22 bu/acre), a low efficiency of N fertilizer usage.

PBDCT The regression coefficients for the PBDCT variable (all P fertilizer except row-applied P) were not significant at the 10% level. These variates were retained because of expected interactions with soil test P and ROWP. From the data in Table 11, the dYIELD/dPBDCT = 0.0160 - 0.000816 PBDCT. The YMAX occurred at 19.6 kg P/ha (40 lb P_2O_5/acre) but the ΔYIELD of 0.2 q/ha from that rate of PBDCT was very low.

NRES1 The NRES1 variable (total N applied the previous year) was the only residual fertilizer variable that was significant in the final model (Table 11). Manu (1979) had selected only PRES1 in his regression model for upland soils in western Iowa. The NRES1 variable had a linear, positive effect on yield. The yield increased 0.014 q/ha per kg N/ha applied in the previous year.

<u>NCODE</u> The crop rotation influence on N availability (NCODE) had a negative, curvilinear effect on yield (Table 11, Figure 4D). The dYIELD/dNCODE = -0.634 + 0.01704 NCODE; YMIN occurred at NCODE = 37, (about fourth-year corn). The NCODE had a mean of 23.0 (second-year corn after meadow), a minimum of 8 (corn following two years of meadow), and a maximum of 40 (corn four or more years after meadow). The ΔYIELD between NCODE = 10 and NCODE = 37 was -6.3 q/ha (-10 bu/acre). This yield response was at average levels of the N fertility variables.

<u>KCODE</u> The crop rotation influence on K availability (KCODE) had a linear, positive effect on corn yield of 0.04 q/ha per unit increase in KCODE from 0 to 60. The least K removal occurs with continuous corn (KCODE = 0) and the most following two or more years of meadow removed for hay or corn removed as silage (KCODE = 60). If K were frequently limiting the corn yield, the expected effect of KCODE would be negative. The effect of KCODE in the regression indicated that it was reflecting N availability more than K availability of the cropping sequence. Because of the correlation between NCODE and KCODE ($r = -0.52$), some distortion of their effects may have occurred in the regression model.

<u>PH1</u> The pH of the plow layer (PH1) had a curvilinear effect on yield (Table 11, Figure 5A). The dYIELD/dPH1 = 1.272 - 0.0660 PH1.

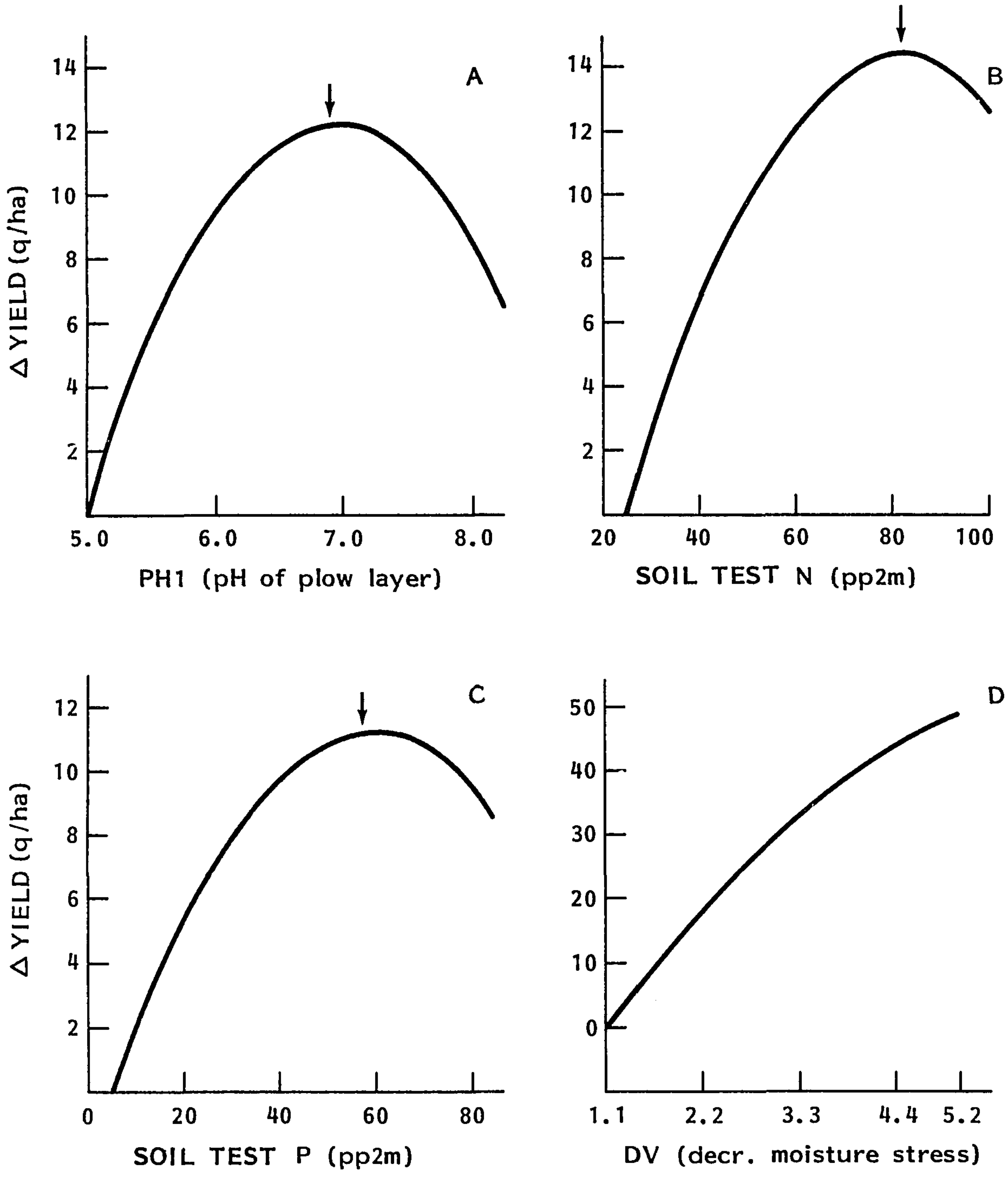


Figure 5. Change in yield (ΔYIELD) with: (A) pH of the plow layer (PH1), (B) soil test N (STN), (C) soil test P (STP1), and (D) moisture stress index (DV)

The YMAX was associated with PH1 = 19.2 (decoded, pH 6.9) which is slightly higher than is considered necessary for maximum corn yield.

The ΔYIELD in Figure 5A as PH1 increased from 0 to 19.2 (decoded, pH 5.0 to 6.92) was 12.2 q/ha (19.4 bu/acre). From PH1 = 10 to 19.2 (pH 6.0 to 6.92), the ΔYIELD was 2.8 q/ha (4.5 bu/acre). Thus, the economic optimum pH level for corn production is between pH 6.0 and pH 6.9. Higher pH levels than 6.9 decreased corn yield at an increasing rate. The ΔYIELD as PH1 increased from 19 (pH 6.9) to 32 (pH 8.2) was -5.4 q/ha (-8.6 bu/acre). The corn yield response to increasing soil pH level in this regression model is in the expected range.

<u>STN</u> In MODEL A-35 (Table 11), STN, soil test N of the plow layer, had a curvilinear effect on yield. The dYIELD/dSTN = 0.705 - 0.00866 STN; YMAX occurred at STN = 81.4 pp2m N, a value in the low end of the high range. From the minimum STN = 24 to STN = 81.4, the ΔYIELD was 14.3 q/ha (23 bu/acre), as shown in Figure 5B. For most soils which had values from 45 to 81, the ΔYIELD varied from 5.7 q/ha (9 bu/acre) to 0.

Soil samples are no longer being tested for STN (mineralizable N) by the Iowa State University Soil Testing Laboratory. All research studies in Iowa, however, have shown that the STN variable has had highly significant effects on corn yield.

<u>STP1</u> The STP1 variable (soil test P of the plow layer) had a highly significant, curvilinear effect on corn yield (Table 11, Figure 5C). The dYIELD/dSTP1 = 0.457 - 0.00778 STP1; YMAX occurred at STP1 = 59 pp2m P.

This STP1 level associated with YMAX is higher than the STP1 value of about 45 pp2m P which has been used to delineate the medium and high levels of STP1. No P fertilizer, except a low maintenance rate, has been recommended at test levels about 45 pp2m P. In this study, the soil samples were taken in the fall at harvest time; these reflected the residual effects from the P fertilizer applied prior to planting. In the research on calibration of yield responses on soil test P levels, the samples were taken prior to fertilizer application. Some shifting of the yield response curve on STP1 levels to the right (a higher STP1 level associated with YMAX) thus would be expected.

As the STP1 level increased from the minimum observed value of 5 pp2m to 59 pp2m (level associated with YMAX), the ΔYIELD (Figure 5C) was 11.3 q/ha (18 bu/acre). From STP1 = 5 to 45 pp2m and from STP1 = 45 to 59 pp2m, the ΔYIELD values were 10.5 q/ha (16.7 bu/acre) and 0.8 q/ha (1.3 bu/acre), respectively. Thus, there was little economic advantage for increasing the STP1 level above 45 to 50 pp2m P.

<u>STK1</u> The STK1 (soil test K of the plow layer) had a small, positive, linear effect on corn yield of 0.0122 q/ha per 1 pp2m increase of K (Table 11). From the minimum STK1 = 35 to STK1 = 200 (high level), ΔYIELD was 2 q/ha. Previous research has shown that little yield response is expected at STK1 levels above 200 pp2m although subsoil K levels also affect the relationship. One also would expect a curvilinear yield response to STK1 levels.

<u>DV</u> The soil moisture stress index (DV), one of the two climatic variables included in this regression study, had a large

curvilinear effect on yield. The dYIELD/dDV = 21.72 - 3.078 DV. The yield increased at a decreasing rate as DV increased from the lowest observed value of 1.1 to DV = 7.1 which was associated with YMAX (Figure 5D). However, the maximum observed DV value in the study was 5.2 which occurred at a Harrison County, irrigated site in 1964. As DV increased from 1.1 to 5.2, the ΔYIELD was 49.2 q/ha (78 bu/acre). The DV variable had the largest effect on yield of all variables.

EXMO The second climatic variable was EXMO (excess moisture index). This index had a mean value of 1.27 and varied from 0 to 14.8. EXMO had a negative, linear effect on yield of 1.4 q/ha per unit increase of EXMO (Table 11). The yield decrease from EXMO = 0 to 14.8 was 20.9 q/ha (33 bu/acre).

Summary of selection of management variables

The management variables included in this study were grouped as environmental, tillage and planting, fertility management, and soil tests of the plow layer. Two modified climatic variables, the soil moisture stress index (DV) and excess moisture index (EXMO), were included in all regressions. The data included in this study were collected from 2657 observations (site-years) in 15 counties from 1957 to 1970. The objective of this first stage of the study was to select the most important management variables for regressing corn yield on management, soil, and climatic variables.

Simple correlation coefficients among 73 original management variables were initially examined. The variables deleted from further analysis because of high correlations or because they could be combined into one variable included time trend, ear weight, moderate and severe root lodging, second-brood corn borer in the stalks and ear shanks, grassy and broadleaf weeds, hill spacing of hill dropped corn, several highly-correlated residual fertilizer variables, and several tillage variables.

In the initial quadratic regression model, MODEL A-1, 49 management variables, 2 climatic variables, and a time period variable were tested. It had 99 variates including 52 linear and 47 squared variates.

Correlations among variates were first examined to determine the model selection steps needed to retain variables which were not correlated greater than $r = \pm 0.60$. Correlations between fertility management variables were particularly high. A series of alternate models was tested to determine which variables could be retained to minimize correlation between variables and yet maximize the R^2 of the prediction equation.

The initial MODEL A-1 had an R^2 of 0.77. Deletion of the BARR and SLKDATE variables reduced the R^2 to 0.61. They were deleted from any further analysis because both were yield components and SLKDATE was highly correlated with PLDATE. In alternate MODELS A-4 to A-27, the most important variables from different groups of correlated variables were selected for further analysis. Stepwise, backward elimination of nonsignificant variates was then performed in MODELS A-28 to A-35. A linear variate was retained, however, regardless of its significance if its squared term was significant.

MODEL A-35 with an R^2 of 0.603 was selected as the final model; it had 42 variates, 27 linear and 15 squared terms. All regression coefficients of the squared variates in the quadratic functions and most of the linear variates in the linear functions were significant at the 1 or 5% level. No variables were correlated greater than r = 0.58 in the final model.

The importance of selected groups of variables was evaluated by deleting them alternately from final MODEL A-35. Their relative importance for explaining yield variation was: 2 climatic variables (mostly DV) > 5 tillage and planting variables (mostly PLDEN) > 4 soil test variables > 6 environmental variables > 5 fertility management variables (mostly NBDCT) > 2 crop rotation variables (mostly NCODE).

The variates in final MODEL A-35 which were retained for testing in the next model series with the soil variables were: (1) linear functions of CRW, SL1, WEEDS, TILLAFT, PLMETH, CULT, ROWSLOPE, TILE, NRES1, KCODE, STK1, and EXMO; and (2) quadratic functions (linear and squared variates) of RL3, CB1, CB2, PLDATE, PLDEN, SLOPE, MANURE, PROW, NBDCT, PBDCT, NCODE, PH1, STN, STP1, and DV.

The effect of each variable on yield was discussed or discussed and illustrated using the regression statistics of final MODEL A-35. Most of the effects of the variables on yield were as expected.

Selection of Soil Variables

Soil variables which had the most important effects on yield, based on the previous research by Henao (1976) and Pena-Olvera (1979), were next selected in the presence of management and climatic variates from

MODEL A-35. The symbols, means, and ranges of the 25 soil and location variables included in this study are shown in Table 12.

The soil variable data after corrections or recoding were repunched on data card 05 (Appendix Table A5); the data were then transformed and transferred to new data card 05 (Appendix Table A6). Depending on the number of years each site was sampled, each new data card 05 was reproduced into the number of cards (card 51) needed to match the number of management and climatic data cards for each site that was used in the regression analysis. The computer program for this program is given in Appendix Table B3. Total PAWC values of the 1.51 m (5 ft) layer computed from the soil moisture program were transferred to new data card 3 (Appendix Table A8) and included as a soil variable. The computer program for this operation is given in Appendix Table B4.

Because of the formatting specification for entering data from the input data cards into the Helarctos II program, a new management card 4 (Appendix Table A9) had to be produced. The management variables that were to be included in this and subsequent models were transferred in a different listing order from new management data card 1 (Appendix Table A4) to card 4. The computer program for this operation is given in Appendix Table B5. The new management card 2 (Appendix Table A4) was retained. The input cards for each year of data from each site for this regression model were then cards 4 (management variables), 2 (management and climatic variables), 3 (PAWC variable), and 51 (soil and location variables). A total of 2657 observations (site-years) were included.

Table 12. Symbols, identification, means, and ranges of the soil and location variables included in the yield regressions, MODEL B series

Symbol	Variable[a]	Mean	Range
PAWC[b]	Plant available water capacity, in. H_2O/5 ft (later transformed to mm/1.51 m)	9.8 (249.2 mm)	2.5-12.2 (64.5-310.9)
TWP	S-N location, coded TWP no. - 65	20.1	2-34
RANGE	E-W location, coded R1E = 0 to R48W = 48	26.5	0-48
EROS	Erosion class, coded 0 to 3	0.68	0-3
THAHOR	Thickness of A horizon, cm	36.4	0-99
OC	Organic carbon in 0-51 cm layer, coded % OC*10	15.7	3-37
DRAIN	Natural internal drainage class, coded 10-90	43.6	10-90
CPL	Clay in plow layer (0-18 cm), %	26.5	5-58
CMAX	Maximum clay in subsoil, %	32.3	4-60
DCMAX	Depth to midpoint of horizon with CMAX, cm	53.6	15-127
SUBGRP	Subsoil group rating, coded 0-6	2.2	0-6
BIO	Biosequence, coded 1 to 5	4.66	1-5
BD	Bulk density of 76-102 cm layer, g/cm^3, coded (BD-1.00)*100	45.1	25-75
LOESS/T	Loess 51-127 cm thick over till or paleosol coded 1, all others = 0	0.058	0-1
TILL	Till parent material coded 1, all others = 0	0.257	0-1
PALEO	Paleosol parent material coded 1, all others = 0	0.027	0-1
SAND	Sand parent material in 0-127 cm profile coded 1, all others = 0	0.072	0-1

[a]More complete descriptions of the variables and coding used are given in Appendix Table A5.

[b]Transformed to mm H_2O/1.51 m profile for later regression analyses.

Table 12. (Continued)

Symbol	Variable[a]	Mean	Range
COLLUV	Colluvium parent material in loess areas coded 1, all others = 0	0.031	0-1
ALLUV	Alluvium parent material (sand > 127 cm) coded 1, all others = 0	0.132	0-1
PHMIN	Minimum pH in subsoil, coded (pH*10)-45	18.1	4-40
DPHMIN	Depth to midpoint of PHMIN horizon, cm	34.5	15-99
DCAL	Depth to top of carbonate layer, cm, coded 152-depth and ≥152 cm = 0	31.0	0-137
PH2	pH of 76-107 cm layer, coded (pH*10)-45	24.9	7-41
STP2	Soil test P of 76-107 cm layer, pp2m	17.8	5-98
STK2	Soil test K of 30-61 cm layer, pp2m	53.2	14-294

<u>Regressions of yield on quadratic functions of management, climatic and soil variables, MODEL B series</u>

Variates included in the correlation and multiple regression analyses for the MODEL B series are listed in Table 13. All 42 management and climatic variates in MODEL A-35, 25 linear variates of the soil and location variables, and 19 squared variates of all soil and location variables except the parent material variables were included in the MODEL B series. Parent material variables had only linear effects since they were coded 0 or 1.

The correlation coefficients between variates were first examined and then model selection proceeded to obtain a final model with low correlations between independent variables, high levels of significance for most regression coefficients, and a high coefficient of multiple determination (R^2). Interpretations of the effects of the selected variables on yield will be given for the final regression model.

<u>Correlation analysis</u> The simple correlation coefficients between linear variates in the MODEL B series greater than $r = \pm 0.45$ are shown in Table 14. Many variables were involved in one or more correlations greater than ± 0.60.

Only two variables (PLDEN and NBDCT) were correlated with YIELD above ± 0.45; these management variables were discussed in the MODEL A series. Other management variables with high correlation coefficients in the MODEL B series were PLDEN and NBDCT ($r = 0.58$) and NCODE and KCODE ($r = -0.52$). These also were discussed previously in the MODEL A series.

Table 13. Variates included in the multiple regressions of yield on the management, climatic, and soil variables, MODEL B series

X_i	Variate	X_i	Variate	X_i	Variate
1	YIELD[a]	30	TWP	59	$PLDATE^2$
2	PLDEN	31	RANGE	60	$MANURE^2$
3	WEEDS	32	EROS	61	$PROW^2$
4	NBDCT	33	THAHOR	62	$PBDCT^2$
5	TILE	34	OC	63	$NCODE^2$
6	RL3	35	DRAIN	64	$SLOPE^2$
7	CRW	36	CPL	65	$PH1^2$
8	SL1	37	CMAX	66	STN^2
9	CB1	38	DCMAX	67	$STP1^2$
10	CB2	39	SUBGRP	68	DV^2
11	PLDATE	40	BIO	69	$PAWC^2$
12	MANURE	41	BD	70	TWP^2
13	PROW	42	LOESS/T	71	$RANGE^2$
14	PBDCT	43	TILL	72	$EROS^2$
15	CULT	44	PALEO	73	$THAHOR^2$
16	TILLAFT	45	SAND	74	OC^2
17	PLMETH	46	COLLUV	75	$DRAIN^2$
18	NCODE	47	ALLUV	76	CPL^2
19	KCODE	48	PHMIN	77	$CMAX^2$
20	NRES1	49	DPHMIN	78	$DCMAX^2$
21	SLOPE	50	DCAL	79	$SUBGRP^2$
22	ROWSLOPE	51	PH2	80	BIO^2
23	PH1	52	STP2	81	BD^2
24	STN	53	STK2	82	$PHMIN^2$
25	STP1	54	$PLDEN^2$	83	$DPHMIN^2$
26	STK1	55	$NBDCT^2$	84	$DCAL^2$
27	DV	56	$RL3^2$	85	$PH2^2$
28	EXMO	57	$CB1^2$	86	$STP2^2$
29	PAWC	58	$CB2^2$	87	$STK2^2$

[a]YIELD is the dependent variable regressed on 52 linear and 34 squared variates.

With the addition of soil variables, the management and soil variables having high correlations were PH1 and PHMIN (r = 0.65), STK1 and RANGE (r = 0.53), and STK1 and STK2 (r = 0.69). Although the pH levels

Table 14. Simple correlation coefficients greater than ±0.45 between yield, management, climatic, and soil variables, MODEL B series

Between variables		r	Between variables		r
YIELD and	PLDEN	.52	RANGE and	STK2	.48
	NBDCT	.46			
			EROS and	THAHOR	-.75
PLDEN and	NBDCT	.58		OC	-.77
NBDCT and	PBDCT	.49	THAHOR and	OC	.70
	NReS1	.50		ALLUV	.49
NCODE and	KCODE	-.52	OC and	DRAIN	.57
NRES1 and	STP1	.46	DRAIN and	CPL	.49
				CMAX	.62
SLOPE and	ROWSLOPE	.50		SUBGRP	.62
	EROS	.66			
	THAHOR	-.50	CPL and	CMAX	.66
	OC	-.59		SUBGRP	.53
	DRAIN	-.46			
			CMAX and	SUBGRP	.92
PH1 and	PHMIN	.65			
	DCAL	.48	BIO and	STP2	-.50
STP1 and	STK1	.46	BD and	TILL	.73
STK1 and	RANGE	.53	ALLUV and	STK2	.53
	STK2	.69			
			PHMIN and	DCAL	.72
EXMO and	CMAX	.54		PH2	.79
	SUBGRP	.61			
			DPHMIN and	PH2	-.56
PAWC and	BD	-.78		STP2	.49
	SAND	-.64			
			DCAL and	PH2	.81
RANGE and	BD	-.53		STP2	-.47
	PHMIN	.58			
	PH2	.56	PH2 and	STP2	-.56

of the surface soils have been altered by liming in eastern Iowa, a high positive correlation between PH1 and PHMIN still occurred. The correlation between STK1 and RANGE showed that soil test K in the plow layer increased from east to west across the state as mean annual precipitation decreased from east to west. This correlation probably has been reduced in recent years by increases in STK1 in eastern Iowa by heavier K fertilization. The soil test K levels in the plow layer and subsoil (STK1 and STK2) were highly correlated because soil test K levels in all layers in the profile were dominantly influenced by the climatic variable.

Correlations involving climatic variables were EXMO and CMAX ($r = 0.54$) and EXMO and SUBGRP ($r = 0.61$). Because only one of the highly correlated pair of variables is usually retained in multiple regression models, these will be examined in the alternate models.

The high correlations between soil variables within the organic matter-related, texture-related and soil pH-related groups are shown in Table 15. The organic matter-related variables (EROS, THAHOR, and OC) were highly intercorrelated as reported by previous investigators (Henao, 1976; Pena-Olvera, 1979). Each of these variables was also highly correlated with the SLOPE variable. As the slopes of the sites increase, more erosion occurs, the A horizon becomes thinner, and the organic carbon content decreases. The DRAIN variable also had moderately high correlations with the SLOPE and OC variables.

Correlations between the texture-related variables (PAWC, DRAIN, CPL, CMAX, and BD) were similar to those previously reported (Henao, 1976). In this study, PAWC was correlated with BD and SAND with coefficients of $r = -0.78$ and $r = -0.64$, respectively. The TILL parent

Table 15. Simple correlation coefficients (r-values) between variables within related soil groups, MODEL B series[a]

Variable	Organic matter-related variables					
	SLOPE	EROS	THAHOR	OC	DRAIN	ALLUV
SLOPE	--	.66	-.50	-.59	-.46	--
EROS		--	-.75	-.77	--	--
THAHOR			--	.70	--	.49
OC				--	.57	--

Variable	Texture-related variables						
	DRAIN	CPL	CMAX	SUBGRP	BD	TILL	SAND
EXMO	--	--	.54	.61	--	--	--
PAWC	--	--	--	--	-.78	--	-.64
DRAIN	--	.49	.62	.62	--	--	--
CPL		--	.66	.53	--	--	--
CMAX			--	.92	--	--	--
BD						.73	--

Variable	Soil pH-related variables						
	RANGE	BIO	PHMIN	DPHMIN	DCAL	PH2	STP2
PH1	--	--	.65	--	.48	--	--
RANGE	--	--	.58	--	--	.56	--
BIO		--	--	--	--	--	-.50
PHMIN			--	--	.72	.79	--
DPHMIN				--	--	-.56	.49
DCAL					--	.81	-.47
PH2						--	-.56

[a]Only the r-values > ±0.45 are shown.

material had a positive correlation with BD of 0.73; the TILL soils have higher bulk density than other parent materials. DRAIN was more highly correlated with CMAX and SUBGRP than with CPL (Table 15). The CMAX and SUBGRP variables were very highly correlated (r = 0.92).

The intercorrelations among the soil pH-related variables are evident from the correlation matrix in Table 15. Highest correlations occurred between the PH1, PH2, PHMIN, and DCAL variables. The RANGE variable was highly correlated with PHMIN and PH2. The STP2 variable was most highly correlated with PH2.

Alternate regression models will be compared to select the most important of the highly correlated variables in the yield regressions. One restriction in selecting the final regression model is that no variables will be included that are correlated greater than ±0.60.

Model selection The model selection steps for the MODEL B series are listed in Table 16. The complete model, MODEL B-1, with all 86 variates listed in Table 13 had an R^2 of 0.638. Addition of the soil variables increased the R^2 from 0.603 in MODEL A-35 to 0.638 in MODEL B-1.

Two management variables, CULT and TILLAFT, had no significance in MODEL B-1 and were deleted from all subsequent models. The highly correlated pH-related variables were tested in alternate MODELS B-2 to B-7. The PH1 and DCAL variables (r = 0.48) were retained in MODEL B-6 and the PHMIN and PH2 variables were deleted (Table 16).

In alternate MODELS B-8 to B-16, the correlated texture-related variables of DRAIN, CPL, CMAX, SUBGRP, PAWC, BD, TILL, and SAND were tested. The DRAIN, CPL, PAWC, and TILL variables were retained in MODEL B-14 and the CMAX, SUBGRP, BD, and SAND variables were deleted. The R^2 was reduced from 0.6378 in MODEL B-6 to 0.6354 in MODEL B-14 by deletion of these variables. MODEL B-14 became the base model for the next selection steps.

Table 16. Model selection steps, MODEL B series

Model no.	No. of X variates	Model selection steps	R^2
B- 1	86	Complete model, all variates listed in Table 13	.6380
2 to 7	78 to 80	Deleted ns CULT and TILLAFT variables and then tested in alternate models the pH-related variables of PH1, PHMIN, PH2, and DCAL; MODEL B-6 was selected	.6314 to .6378
6	80	Deleted PHMIN, PH2, CULT, and TILLAFT variables from MODEL B-1	.6378
8 to 16	72 to 76	In alternate models, tested correlated texture-related variables of DRAIN, CPL, CMAX, SUBGRP, PAWC, TILL, BD, and SAND; MODEL B-14 was selected	.6334 to .6359
14	73	Deleted CMAX, SUBGRP, BD, and SAND variables from MODEL B-6	.6354
17 to 24	67 to 69	In alternate models, tested correlated organic matter-related variables of SLOPE, EROS, THAHOR, and OC and correlated STK1 and STK2 variables; MODEL B-23 was selected	.6322 to .6344
23	67	Deleted EROS, OC, and STK2 variables from MODEL B-14; no soil variables correlated greater than ±0.53	.6342
25 to 30	63 to 57	Deleted stepwise the ns variates of $PROW^2$, $DCMAX^2$, BIO^2, $STP2^2$, $DPHMIN^2$, LOESS/T, ALLUV, COLLUV, and DCMAX from MODEL B-23; MODEL B-30 with 58 variates and R^2 = .6334 was selected as the final model	.6339 to .6334

The correlated organic matter-related variables (SLOPE, EROS, THAHOR, and OC) and the correlated variables of STK1 and STK2 were tested in alternate MODELS B-17 to B-24. The SLOPE, THAHOR, and STK1 variables were retained in MODEL B-23 (R^2 = 0.6342) and the EROS, OC, and STK2 variables were deleted. No soil variables were correlated greater than ±0.53 in MODEL B-23.

In MODELS B-25 to B-30 (Table 16), nine nonsignificant variates were deleted stepwise from MODEL B-23. The R^2 was reduced from 0.6342 in MODEL B-23 to 0.6334 in the final selected MODEL B-30. Addition of selected soil and location variates increased the R^2 from 0.6030 in MODEL A-35 to 0.6334 in final MODEL B-30.

Interpretation of the effects of the variables on yield   The regression statistics of the selected final quadratic MODEL B-30 of yield on management, climatic, and soil variables are given in Table 17. Its analysis of variance is listed in Appendix Table A10. The effects of the variables on yield are also summarized in Table 17. The 58 variates retained in MODEL B-30 included 37 linear and 21 squared variates. All squared variates were significant at the 1% or 5% level except PBDCT and PAWC which were significant at the 15% level. Variables with only linear variates which were retained in the model but were not significant at the 5% level were PLMETH (10% level), ROWSLOPE and DPHMIN (15% level), and TILL and STP2 (not significant at the 15% level). The TILL and STP2 variates were retained in the final model to test some of their interactions in the next series of models. Three variates (CULT, TILLAFT, and $PROW^2$) which had been included in MODEL A-35 were deleted in MODEL B-30 because of nonsignificance.

Most of the management and climatic variables had similar effects on yield in MODEL B-30 (Table 17) as they had in MODEL A-35 (Table 11).

Table 17. Regression statistics of the selected final quadratic model of yield on management, climatic, and soil variables, MODEL B-30[a]

Variable[b]	b_i Linear	b_i Quadratic	Interpretation of the effect of the variable on yield[c]
			Management variables
PLDEN	0.170**	-0.000137**	YMAX at 620 or 62,000 plants/ha (25,100 stalks/A)
PLDATE	0.110	-0.00681**	YMAX at 8 or April 28
PLMETH	-0.93[++]	--	Y was 0.9 q/ha less in hilled than in drilled corn
WEEDS	-0.0283**	--	Y decr. 0.03 q/ha per 10 kg/ha increase in weeds
RL3	0.0341	-0.000919*	YMAX at 19% root lodged
CRW	-0.344**	--	Y decr. 0.34 q/ha per unit from 10 to 54
SL1	-0.246**	--	Y decr. 0.25 q/ha per 1% increase in stalk lodging
CB1	0.607**	-0.0318**	YMAX at 9.5 cavities/10 plants (moderate CB1)
CB2	0.162**	-0.00167**	YMAX at 48.5 cavities/10 plants (mod.-severe CB2)
ROWSLOPE	-0.217[+]	--	Y decr. 0.22 q/ha for each 1% increase in row slope
TILE	0.0647**	--	Y incr. 0.065 q/ha per 1 m closer to tile
MANURE	0.202**	-0.00398*	YMAX at 25.4 MT/ha (11.3 T/A)
NBDCT	0.0903**	-0.000187**	YMAX at 241 kg N/ha (215 lb N/A)
PBDCT	0.0885*	-0.00145[+]	YMAX at 30.5 kg P/ha (62 lb P_2O_5/A)
PROW	0.0830*	--	Y incr. 0.08 q/ha per kg P/ha
NRES1	0.0106*	--	Y incr. 0.011 q/ha per kg N/ha in previous year
NCODE	-0.568**	0.00745**	YMIN at 38 (4th-year corn)
KCODE	0.0437*	--	Y incr. 0.044 q/ha per unit of KCODE from 0 to 60

[a]Intercept = -68.3; R^2 = 0.633; no. of obs. = 2657; and no. of variates = 58.

[b]Means, ranges, and units of the variables are given in Tables 5 and 12.

[c]YMAX = maximum yield; YMIN = minimum yield; and Y = yield.

Table 17. (Continued)

Variable[b]	b_i Linear	Quadratic	Interpretation of the effect of the variable on yield[c]
		Management: soil tests of plow layer	
PH1	0.838**	-0.0181**	YMAX at PH1 = 23.1 (pH of 7.3)
STN	0.621**	-0.00363**	YMAX at 86 pp2m (high soil test N)
STP1	0.378**	-0.00337**	YMAX at 56 pp2m (high soil test P)
STK1	0.0143**	--	Y incr. 0.014 q/ha per increase of 1 pp2m K
		Climatic indexes	
DV	19.65**	-1.458**	YMAX at 6.7 (no stress, highest observed = 5.2)
EXMO	-1.071**	--	Y decr. 1.07 q/ha per unit increase from 0 to 15
		Soil variables	
PAWC	-1.897^{+}	0.105^{+}	YMIN at 9.0 in. H_2O/5 ft (229 mm/1.51 m)
TWP	0.117	-0.00926**	YMAX at 6.3, decoded TWP 71N
RANGE	-0.439**	0.00723**	YMIN at RANGE 30W
SLOPE	0.546*	-0.0318*	YMAX at 8.6% slope
THAHOR	0.145**	-0.00115*	YMAX at THAHOR = 63 cm (25 in.)
DRAIN	0.392**	-0.00404**	YMAX at DRAIN = 48.5, somewhat poorly drained
CPL	0.360^{++}	-0.00721*	YMAX at 25% clay
BIO	0.734*	--	Y incr. 0.73 q/ha per unit from 1 to 5
TILL	-1.02	--	Y 1.0 q/ha less on till soils than average of others
PALEO	-4.23*	--	Y 4.2 q/ha less on paleosols than average of others
DPHMIN	0.0288^{+}	--	Y incr. 0.029 q/ha per cm increase to PHMIN layer
DCAL	0.0604**	-0.000632**	YMAX at 48 cm, decoded 104 cm (41 in.) to calc. layer
STP2	0.0156	--	Y incr. 0.016 q/ha per 1 pp2m increase of STP2

The levels of NBDCT, PBDCT, and PH1 associated with maximum yield were somewhat different in MODEL B-30 than in MODEL A-35. The PROW variable had a significant, linear effect on corn yield in MODEL B-30 but only a weak, curvilinear effect in MODEL A-35. The effects of only these management variables and the effects of all soil variables on corn yield will be discussed in the following subsections.

<u>NBDCT</u>, <u>PBDCT</u>, <u>PROW</u>, <u>and</u> <u>PH1</u> The curvilinear effect of NBDCT on yield (Table 17) showed that YMAX (maximum yield) occurred at 241 kg N/ha (215 lb N/acre). This N rate is more reasonable than the 291 kg N/ha (259 lb N/acre) associated with YMAX in MODEL A-35.

The curvilinear effect of PBDCT on yield was more significant in MODEL B-30 than in MODEL A-35. The P rate associated with YMAX (Table 17) was 30.5 kg P/ha (62 lb P_2O_5/acre) but was only 19.6 kg P/ha (40 lb P_2O_5/acre) in MODEL A-35 (Table 11).

PROW had a linear effect on yield in MODEL B-30 of 0.083 q/ha per kg P/ha applied. A row application of 21 kg P/ha thus increased yield by 1.7 q/ha (2.8 bu/acre). In MODEL A-35, YMAX occurred at PROW = 21 kg P/ha (Table 11); the yield increase from this rate was about 0.8 q/ha (1.2 bu/acre), less than half the increase estimated from MODEL B-30.

In MODEL B-30, YMAX occurred at a pH of 7.3 (Table 17). This was higher than the pH of 6.9 which was associated with YMAX in MODEL A-35 (Table 11). YMAX at a pH of 7.3 for corn is higher than that reported by most researchers.

<u>PAWC</u> The partial derivative of YIELD with respect to PAWC (MODEL B-30, Table 17) is dYIELD/dPAWC = -1.897 + 0.210 PAWC; YMIN

occurred at PAWC = 9.0 in. H_2O/5 ft or 229 mm H_2O/1.51 m layer. The regression coefficients for both linear and squared variates of PAWC were significant at only the 15% level. The effect of PAWC on yield in this model is much different from the effects reported by Henao (1976) and Pena-Olvera (1979), who found that PAWC had a positive linear effect on yield modified by some interactions.

<u>TWP</u> The TWP variable had a curvilinear effect on yield (Table 17, Figure 6A). The dYIELD/dTWP = 0.117 - 0.01852 TWP; YMAX occurred at coded TWP = 6.3 or decoded TWP71N (southern edge of Adams County). This response was similar to that reported by Henao (1976).

The ΔYIELD between TWP67N and TWP71N was 0.16 q/ha (0.26 bu/acre). From TWP71N to TWP100N the ΔYIELD was -7.7 q/ha (-12.3 bu/acre) with all other variables held constant. The differences in temperature, length of growing season, and maturities of the corn hybrids may have caused these effects of TWP (S-N location) on corn yield.

<u>RANGE</u> The RANGE variable had a highly significant curvilinear effect on corn yield (Table 17, Figure 6B). The dYIELD/dRANGE = -0.439 + 0.01446 RANGE; YMIN was associated with RANGE = 30 (eastern Greene County). The ΔYIELD from Range 1E (coded RANGE = 0) to RANGE 30W was -6.6 q/ha (-10.5 bu/acre) as shown in Figure 6B. From Range 30W to 48W, the ΔYIELD was 2.3 q/ha (3.7 bu/acre).

These responses were similar to those obtained by Henao (1976). These effects of RANGE on corn yield are not completely realistic; all other variables, including DV, are held constant in the quadratic model although several vary with RANGE due to the influence of the highly

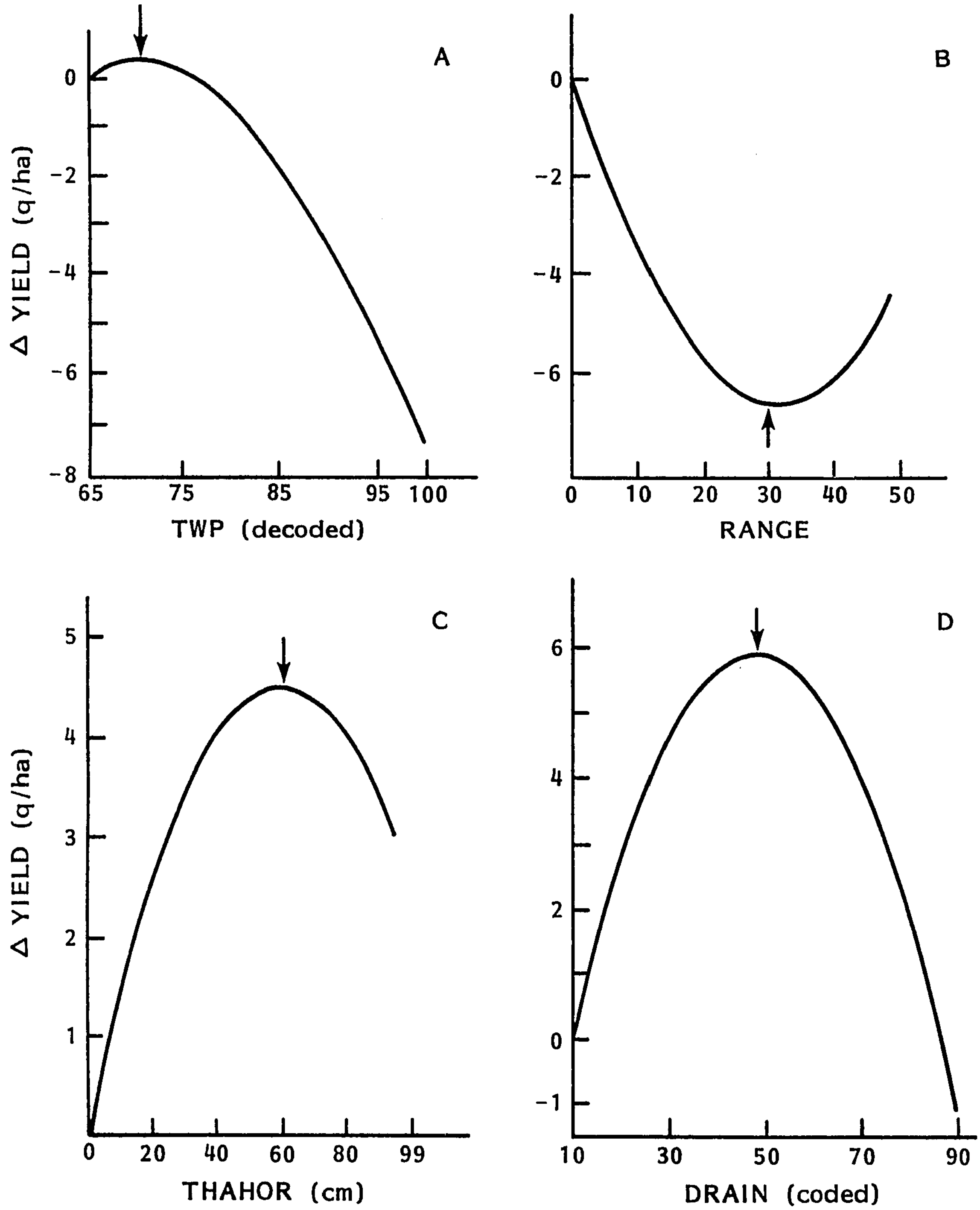


Figure 6. Change in yield (ΔYIELD) with: (A) township number, S-N location (TWP), (B) range number, E-W location (RANGE), (C) thickness of A horizon (THAHOR), and (D) drainage class (DRAIN)

correlated climatic factor of precipitation.

SLOPE The average slope of the site in this study was 4.2% and ranged from 0 to 21% (Table 5). The influence of SLOPE on the yield in MODEL B-30 (Table 17) was curvilinear. The dYIELD/dSLOPE = 0.546 - 0.0636 SLOPE; YMAX occurred at SLOPE = 8.6%, which was higher than the 6.8% in MODEL A-35 (Table 11). The ΔYIELD was 2.3 q/ha (3.7 bu/acre) as SLOPE increased from 0 to 8.6%. As SLOPE increased from 8.6% to 21%, the ΔYIELD was -4.9 q/ha (-7.8 bu/acre).

THAHOR Thickness of A horizon (THAHOR) had a curvilinear effect on yield (Table 17, Figure 6C). The dYIELD/dTHAHOR = 0.145 - 0.00230 THAHOR; YMAX occurred at THAHOR = 63 cm (25 in.). The mean THAHOR was 36 cm (Table 12) which was much lower than that associated with YMAX. The yield increase as THAHOR increased from 0 cm (severely eroded) was less than expected. The ΔYIELD between THAHOR = 0 and THAHOR = 63 was 4.6 q/ha (7.3 bu/acre). The relatively few sites with THAHOR > 63 cm were colluvium, alluvium, and lacustrine parent materials.

DRAIN The curvilinear yield response to DRAIN (drainage class) in MODEL B-30 (Table 17) is shown in Figure 6D. The drainage class was coded from 10 = excessive to 90 = very poor (Appendix Table A5).

The dYIELD/dDRAIN = 0.392 - 0.00808 DRAIN; YMAX occurred at DRAIN = 48.5 (somewhat poorly drained) which was slightly poorer drainage than that reported by Henao (1976). The ΔYIELD between DRAIN = 10 (excessive) to DRAIN = 48.5, associated with YMAX, was 6.0 q/ha (9.6 bu/acre). The ΔYIELD was -7.0 q/ha (-11.1 bu/acre) as the drainage became poorer from DRAIN = 48.5 to DRAIN = 90 (very poor).

CPL The CPL variable (percentage clay in the plow layer) had a curvilinear effect on yield in MODEL B-30, as shown in Figure 7A. The dYIELD/dCPL = 0.360 - 0.01442 CPL; YMAX occurred at 25% clay. Henao (1976) had reported that yield decreased at an increasing rate as CPL increased.

The average CPL was 26.5%; the observed values in this study ranged from 5 to 58% (Table 12). The ΔYIELD from 5% to 25% was 2.9 q/ha (4.6 bu/acre). From 25% to 58% clay, the ΔYIELD was -7.9 q/ha (-12.6 bu/acre).

BIO The BIO (biosequence) variable had a positive, linear effect on corn yield; yield increased 0.73 q/ha (1.2 bu/acre) per unit increase of coded BIO. The ΔYIELD between the forest-derived soils (BIO = 1) and prairie-derived soils (BIO = 5) was 2.9 q/ha (4.6 bu/acre). This difference was less than expected.

TILL and PALEO TILL (glacial till) and PALEO (paleosol) were the only parent material groups retained in MODEL B-30. Both had negative, linear effects on yield in the model but only PALEO had a significant effect. The TILL variable was retained because it may be involved in interactions with other variables. The regression coefficients of MODEL B-30 showed that paleosols had 4.2 q/ha (6.7 bu/acre) less corn yield than the average of all other soils and till-derived soils had 1.0 q/ha (1.6 bu/acre) less yield than other soils.

DPHMIN In MODEL B-30 (Table 17), DPHMIN (depth to minimum pH) had a positive, linear effect on yield which was only significant at

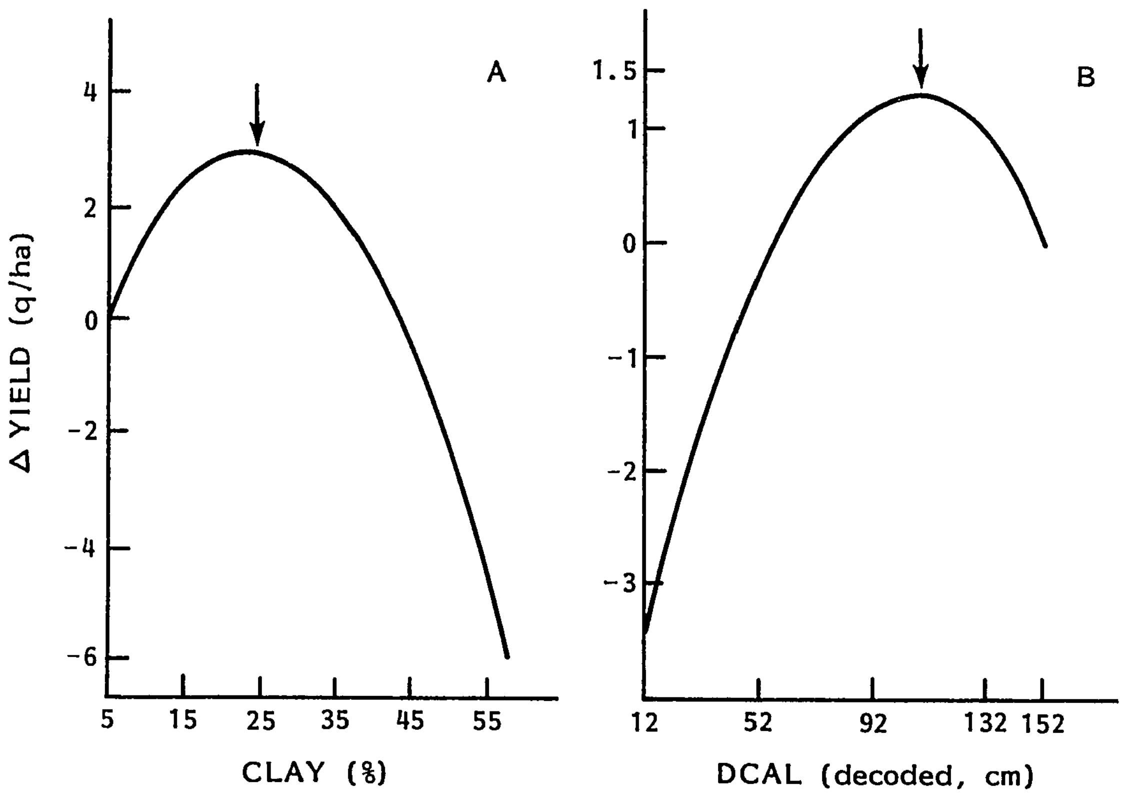


Figure 7. Change in yield (ΔYIELD) with: (A) percentage clay in the plow layer (CPL), and (B) depth to the calcareous layer (DCAL)

the 15% level. The yield increased 0.029 q/ha per cm increase to the PHMIN layer. A similar yield response to DPHMIN was also obtained by Henao (1976). The DPHMIN variable reflects the degree of weathering that has occurred in Iowa soils. It was intercorrelated with several soil variables other than STP2 with which it had the highest simple correlation ($r = 0.49$). Mosavati (1979) found that DPHMIN was significantly related to the TWP, RANGE, SLOPE, THAHOR, DRAIN, BIO, DCAL, and STP2 variables included in this model.

DCAL The DCAL variable (depth to the top of the calcareous layer in the subsoil) was coded as 152 cm - depth to calcareous layer in cm (Appendix Table A5). If deeper than 152 cm (60 in.), DCAL was set equal to 0. This coding, although desirable statistically, does cause confusion in the interpretation of the DCAL effect on yield.

In MODEL B-30 (Table 17), the dYIELD/dDCAL = 0.0604 - 0.001264 DCAL; YMAX occurred at 48 cm or, decoded, 104 cm (41 in.) to the top of the calcareous layer. Yield increased slightly as the decoded depth to the calcareous layer decreased from 152 cm to 104 cm, where YMAX occurred (Figure 7B). As depth to the calcareous layer became more shallow than 104 cm, yield decreased at an increasing rate. The ΔYIELD from decoded DCAL = 152 to 104 cm was 1.44 q/ha (2.3 bu/acre). From decoded DCAL = 104 to 15 cm (top of the subsoil), the ΔYIELD was -5.0 q/ha (-8.0 bu/acre).

As the decoded depth to the calcareous layer decreased, the pH of the upper layers increased as shown by the correlations between coded DCAL and PHMIN ($r = 0.72$) and coded DCAL and PH1 ($r = 0.48$). As decoded

DCAL decreased from 152 to 104 cm, the increased pH of the upper layers increased availability of most nutrients except P and had a favorable effect on yield. But, as decoded DCAL became more shallow, the pH of the upper layers became increasingly higher which decreased nutrient availability, particularly that of soil P, and decreased yield. Pena-Olvera (1979) reported a similar effect on DCAL on corn yield.

<u>STP2</u> The STP2 variable (soil test P of the 76-107 cm or 30-42 in. layer) had a positive, linear effect on yield which was not significant at the 15% level. The yield was increased 0.016 q/ha (0.025 bu/acre) as the STP2 level increased 1 pp2m. This response was in the expected direction. STP2 had moderately-high correlations with the BIO, DPHMIN, and DCAL variables retained in the model.

<u>Summary of selection of soil variables</u>

For the MODEL B series of regressions, soil variables which had significant effects on corn yield in previous studies were tested in the presence of the 42 management and climatic variates from final management MODEL A-35. Data for the 25 soil and location variables were collected from the 678 sites where yield data had been obtained. The initial quadratic regression model of the MODEL B series included linear variates of all soil and location variables and 19 squared variates of all except the 6 parent material variables which were dummy variables coded 0 or 1.

The correlations between variables were first examined. Many soil variables were involved in one or more correlations greater than ±0.60.

Alternate regression models were used to select the most important variables of the highly correlated pairs or groups variables for retention in the yield regressions. The restriction that no variables correlated greater than ± 0.60 were to be included in the final regression model was again applied.

The complete model with 86 variates, MODEL B-1, had an R^2 of 0.638. The highly correlated pH-related, texture-related, and organic matter-related soil variables were tested in alternate MODELS B-2 to B-24. After these variable selection steps, no soil variables were correlated greater than $r = \pm 0.53$. The nonsignificant variates were then deleted stepwise in MODELS B-25 to B-30. MODEL B-30 with 58 variates was the final model; addition of the selected soil variates increased the R^2 from 0.603 in MODEL A-35 to 0.633 in MODEL B-30. Three management variates (CULT, TILLAFT, and $PROW^2$) were deleted because of nonsignificance.

The final quadratic MODEL B-30 of yield on management, climatic, and soil variables had 37 linear and 21 squared variates. Most squared variates and variates of linear functions were significant at the 1% or 5% level. The few linear variates not significant at the 10% level were retained to test their interactions in the next series of models.

The variables retained in final MODEL B-30 for inclusion in the next series of interaction models included: (1) linear functions (linear variates only) of PLMETH, WEEDS, CRW, SL1, ROWSLOPE, TILE, PROW, NRES1, KCODE, STK1, EXMO, BIO, TILL, PALEO, DPHMIN, and STP2; and (2) quadratic functions (linear and squared variates) of PLDEN, PLDATE, RL3, CB1, CB2, MANURE, NBDCT, PBDCT, NCODE, PH1, STN, STP1, DV, PAWC, TWP, RANGE, SLOPE, THAHOR, DRAIN, CPL, and DCAL.

Most of the management and climatic variables had similar effects on yield as they had in MODEL A-35. The levels of NBDCT, PBDCT, and PH1 associated with maximum yield, however, were somewhat different in this model than in MODEL A-35. All of the soil variables had similar effects on yield as had been reported by Henao (1976) except PAWC; minimum yield was associated with a medium level of PAWC instead of a low level, as expected. The effects of the soil variables on yield were interpreted and most of the curvilinear effects were illustrated.

Selection of Interaction Variates

Interactions between the management, climatic and soil variables retained in final MODEL B-30 were next selected in the following steps. All possible interactions between the 37 variables in MODEL B-30 and the ALLUV variable added were 703. Not all of these could be tested because of limited funds. Several were deleted initially because the interaction could not occur such as between parent material variables or because of limited range of observed values such as alluvial parent material which had little variation in slope, paleosol units which had little range in subsoil P, and the soils in western Iowa which had little forest influence.

Henao (1976) had tested many of these interactions and Pena-Olvera (1979) also had tested many but his observations were limited to western Iowa. Any interactions that Henao had tested and found not significant were deleted initially; those that showed some significance in preliminary models were retained and tested. Interactions that Pena-Olvera had tested and were not significant were deleted if there was little chance that they might be significant in the state-wide data. Other interactions that were logical based on *a priori* agronomic information were retained for testing but those which were not likely to be important were deleted.

Regressions of yield on quadratic functions with interactions, MODELS C, D, E, F, and G series

Linear and squared variates retained in MODEL B-30 plus the ALLUV variable were used as the base set in all models for selection of interactions. These variates are listed in Table 18. The ALLUV variable was added to the base set and retested because Henao (1976) and Pena-Olvera (1979) had found significant interactions involving ALLUV parent material.

With 60 variates as a base set, including YIELD as the dependent variable (Table 18), only 39 interaction variates could be tested in each model series. The Helarctos II program which was used for this study can only accommodate a maximum of 100 variates, or in this case 99 variates plus one dummy variate, the 51st transformed variate.

A total of 195 interactions were selected to be tested. These were randomly assigned to the MODELS C, D, E, F and G series, with each model having 39 interaction variates. The distributions of the variates among the five series of models are given in Table 19.

The most significant interactions in each of the model series were selected by backward, stepwise elimination of nonsignificant variates. The number of variates and the R^2 of the complete and reduced models

Table 18. Base set of linear and squared variates included in the regression models to select interaction variates, MODELS C to G series

X_i	Variate	X_i	Variate	X_i	Variate
1[a]	YIELD	21	PH1	41	$NBDCT^2$
		22	STN	42	$RL3^2$
2	PLDEN	23	STP1	43	$CB1^2$
3	WEEDS	24	STK1	44	$CB2^2$
4	NBDCT	25	DV	45	$PLDATE^2$
5	TILE	26	EXMO	46	$MANURE^2$
6	RL3	27	PAWC	47	$PBDCT^2$
7	CRW	28	TWP	48	$NCODE^2$
8	SL1	29	RANGE	49	$SLOPE^2$
9	CB1	30	THAHOR	50	$PH1^2$
10	CB2	31	DRAIN	51	STN^2
11	PLDATE	32	CPL	52	$STP1^2$
12	MANURE	33	BIO	53	DV^2
13	PROW	34	TILL	54	$PAWC^2$
14	PBDCT	35	PALEO	55	TWP^2
15	PLMETH	36	ALLUV	56	$RANGE^2$
16	NCODE	37	DPHMIN	57	$THAHOR^2$
17	KCODE	38	DCAL	58	$DRAIN^2$
18	NRES1	39	STP2	59	CPL^2
19	SLOPE			60	$DCAL^2$
20	ROWSLOPE	40	$PLDEN^2$		

[a]YIELD was the dependent variable regressed on 38 linear and 21 squared variates plus selected interaction variates.

are given in Table 20.

Deletion of 29 to 33 interactions from each of the complete models reduced the R^2-values about 0.005 in each of the five models. The R^2-values of the reduced models were only 0.01 to 0.02 higher than the R^2 of 0.633 for the final quadratic model, MODEL B-30.

The regression coefficients and t-values of almost all of the linear and squared variates included in the base set were fairly stable

Table 19. Interaction variates tested in the multiple regression MODELS C to G series

X_i	Interaction variates tested in the following models				
	MODEL C	MODEL D	MODEL E	MODEL F	MODEL G
61	PLDEN*NBDCT	PLDEN*PLDATE	PLDEN*CB1	PLDEN*CB2	PLDEN*MANURE
62	*TWP	*PLMETH	*RANGE	*NRES1	*PBDCT
63	WEEDS*TWP	*DV	WEEDS*DV	*THAHOR	WEEDS*STN
64	NBDCT*CB1	WEEDS*NBDCT	NBDCT*CB2	WEEDS*EXMO	NBDCT*PLDATE
65	*NRES1	NBDCT*PBDCT	*STN	NBDCT*MANURE	*NCODE
66	*STK1	*THAHOR	*STP1	*PROW	*RANGE
67	TILE*DRAIN	TILE*EXMO	*DV	*PH1	*CPL
68	RL3*DV	CRW*CB1	RL3*PAWC	*PAWC	RL3*CRW
69	CRW*PLDATE	*THAHOR	CRW*STP1	RL3*NCODE	CRW*SLOPE
70	SL1*KCODE	CB1*CB2	*DV	CRW*PBDCT	CB1*STN
71	CB1*TWP	CB2*RANGE	CB1*PH1	*RANGE	*PAWC
72	CB2*PAWC	PLDATE*DV	*THAHOR	CB1*DV	CB2*TWP
73	PLDATE*PROW	MANURE*STP1	PLDATE*MANURE	*RANGE	PLDATE*DRAIN
74	MANURE*PROW	*THAHOR	MANURE*PBDCT	PLDATE*PBDCT	MANURE*PH1
75	*NCODE	PROW*KCODE	*STK1	*TWP	*DV
76	*STN	*STP1	PROW*NCODE	MANURE*KCODE	PROW*TWP
77	PROW*PBDCT	PBDCT*NRES1	*STK1	PROW*PH1	*CPL
78	PBDCT*PH1	*TWP	*RANGE	PBDCT*STK1	PBDCT*KCODE
79	*DRAIN	*TILL	PBDCT*SLOPE	*RANGE	*STP1
80	*STP2	NCODE*STN	--[a]	NCODE*SLOPE	*DV
81	NCODE*PH1	*RANGE	*DPHMIN	*DV	NCODE*NRES1
82	*STP1	*DRAIN	NCODE*STK1	NRES1*STK1	*DCAL
83	KCODE*DV	KCODE*STK1	*TWP	SLOPE*STN	KCODE*THAHOR

[a]PBDCT*CPL variate lost due to formatting error.

Table 19. (Continued)

X_i	Interaction variates tested in the following models				
	MODEL C	MODEL D	MODEL E	MODEL F	MODEL G
84	NRES1*SLOPE	NRES1*RANGE	NCODE*THAHOR	SLOPE*STP1	NRES1*THAHOR
85	*STN	*STP2	KCODE*NRES1	PH1*STP1	SLOPE*DV
86	SLOPE*RANGE	SLOPE*PH1	NRES1*STP1	*DPHMIN	*DPHMIN
87	*DCAL	*PAWC	SLOPE*ROWSL	STN*STP1	PH1*STN
88	PH1*THAHOR	*DRAIN	*CPL	*THAHOR	*BIO
89	STN*STK1	PH1*CPL	PH1*TWP	STP1*STP2	*ALLUV
90	DUMMY	DUMMY	DUMMY	DUMMY	DUMMY
91	STP1*DV	PH1*DCAL	PH1*DRAIN	STK1*CPL	STP1*STK1
92	*TILL	STN*RANGE	STN*TWP	DV*DRAIN	*RANGE
93	STK1*DRAIN	STP1*TWP	*ALLUV	*BIO	*THAHOR
94	DV*EXMO	*DPHMIN	STP1*CPL	PAWC*THAHOR	STK1*TWP
95	PAWC*TWP	STK1*DV	DV*RANGE	TWP*RANGE	*TILL
96	RANGE*THAHOR	*BIO	PAWC*RANGE	*ALLUV	DV*TWP
97	*ALLUV	DV*PAWC	THAHOR*BIO	THAHOR*CPL	EXMO*ALLUV
98	THAHOR*DPHMIN	TWP*THAHOR	DRAIN*DPHMIN	DRAIN*BIO	PAWC*DRAIN
99	CPL*BIO	DRAIN*ALLUV	TILL*DCAL	TILL*DPHMIN	RANGE*DPHMIN
100	*DPHMIN	CPL*ALLUV	DCAL*STP2	DCAL*ALLUV	BIO*STP2

Table 20. R^2-values of complete and reduced regression models for selecting interaction variates, MODELS C to G series

Model no.	No. of X variates	Identification	R^2
C- 1	98	Complete model, base set of 38 linear and 21 squared variates (Table 18) plus 39 interaction variates (Table 19)	.649
C-10	66	Reduced model, base set plus 7 interaction variates by stepwise backward selection	.645
D- 1	98	Complete model, base set plus 39 interaction variates (Table 19)	.659
D-10	68	Reduced model, base set plus 9 interaction variates	.653
E- 1	98	Complete model, base set plus 39 interaction variates (Table 19)	.656
E- 9	69	Reduced model, base set plus 10 interaction variates	.651
F- 1	98	Complete model, base set plus 39 interaction variates (Table 19)	.653
F- 9	69	Reduced model, base set plus 10 interaction variates	.649
G- 1	98	Complete model, base set plus 39 interaction variates (Table 19)	.647
G-10	65	Reduced model, base set plus 6 interaction variates	.641

(similar) in all five model series. Instability of the regression coefficients in different models may reflect high intercorrelations among variables although the coefficients of linear variates will vary as interactions are added or deleted.

Interaction variates significant at the 0.01 to 0.02 level were retained in each final model for testing in the next model series. These are listed in Table 21; many of these were also significant in

Table 21. Significance of the interaction variates retained in the final reduced models, MODELS C to G series[a]

Model no.	Variate	t	Model no.	Variate	t
C-10	NBDCT*STK1	-2.75	E- 9	RL3*PAWC	-3.21
	RL3*DV	-2.93		CRW*STP1	-2.87
	CB1*TWP	-2.94		STN*TWP	-2.44
	KCODE*DV	2.94		DV*RANGE	-3.22
	SLOPE*DCAL	-5.21		DCAL*STP2	4.30
	STP1*DV	3.91			
	PAWC*TWP	2.47	F- 9	PLDEN*CB2	-4.16
				NBDCT*MANURE	-2.33
D-10	PLDEN*DV	6.87		CRW*PBDCT	-2.61
	NBDCT*THAHOR	-2.52		CB1*DV	4.07
	CB1*CB2	-3.18		SLOPE*STN	4.11
	MANURE*STP1	-2.83		PH1*DPHMIN	2.38
	NCODE*STN	3.10		DV*DRAIN	-3.05
	NRES1*RANGE	-2.64		*BIO	-3.12
	SLOPE*PH1	-4.48		THAHOR*CPL	-2.85
	PH1*DCAL	-2.60		DRAIN*BIO	2.33
	DV*PAWC	-4.77			
			G-10	NBDCT*NCODE	4.48
E- 9	PLDEN*CB1	-3.21		*RANGE	-2.39
	WEEDS*DV	-2.47		CB1*PAWC	2.54
	NBDCT*CB2	-4.56		MANURE*DV	2.69
	*STN	-3.70		PBDCT*STP1	-3.50
	*DV	4.56		STP1*THAHOR	-3.10

[a]All interaction variates retained in the final models had t-values >±2.3; $t_{.05} = 1.96$, $t_{.02} = 2.33$, and $t_{.01} = 2.58$.

the models of Henao (1976). This rigid selection was followed to reduce the total number of interactions to 42 which was the number that could be included in the next model. The interaction variates that were significant at the 0.02 to 0.10 level prior to deletion are listed in Table 22; these will be retested at a later stage. The selected

Table 22. Significance of interaction variates prior to deletion in the final stages of model selection, MODELS C to G series

Model no.	Variate	t[a]	Model no.	Variate	t
C-9	NBDCT*CB1	2.10	E-7	NBDCT*STP1	-1.82
				PROW*NCODE	1.82
D-7	CB2*RANGE	1.99	E-8	STN*ALLUV	-2.26
	PLDATE*DV	-1.97			
	PBDCT*NRES1	-2.01	F-6	PLDEN*THAHOR	-1.76
	NCODE*DRAIN	-1.90		PROW*PH1	1.89
				DCAL*ALLUV	1.78
D-8	KCODE*STK1	-2.19	F-7	PLDATE*TWP	-1.96
D-9	STK1*BIO	-2.27			
			G-7	PH1*BIO	-1.86
E-5	PH1*TWP	1.84	G-8	NCODE*DCAL	1.92
E-6	MANURE*STK1	-1.84		NRES1*THAHOR	-1.80
	NCODE*STK1	1.70		BIO*STP2	1.87

[a] $t_{.10} = 1.65$, $t_{.05} = 1.96$, and $t_{.02} = 2.33$.

interactions from these models will not be discussed because their significance may change in subsequent models.

__Regressions of yield on quadratic functions and selected interactions, MODEL H series__

The 42 interactions significant at the 1 to 2% level selected in the MODELS C to G series (Table 21) were then combined and tested in the MODEL H series. The PBDCT*CPL interaction variate which was lost due to a formatting error was also included.

Five of the linear and squared variates (PLMETH, ROWSLOPE, TILL, ALLUV, and $SLOPE^2$) were not significant in any of the MODELS C to G series and were deleted from the MODEL H series. Their deletion provided 43 spaces for testing interactions and one more space for the transformation of the PAWC variable to metric units.

Variates included in the MODEL H series are listed in Table 23. The initial model had 34 linear, 20 squared, and 43 interaction variates. The model selection steps from the initial MODEL H-1 to the final MODEL H-11 are outlined in Table 24. The squared and interaction variates were retained if significant at the 5% level; a linear variate was retained in the model regardless of its significance if its squared variate or one of its interaction variates was significant at the 5% level.

The complete model (MODEL H-1) with all variates listed in Table 23 had an $R^2 = 0.680$ (Table 24). After a series of stepwise, backward eliminations of nonsignificant variates as described in Table 24, MODEL H-11 was selected as the final model. Deletion of 23 variates (17 interactions, 5 squared terms, and 1 linear term) decreased the R^2-value from 0.680 in MODEL H-1 to 0.677 in final MODEL H-11. The addition of the significant interaction variates in MODEL H-11 increased the R^2 about 0.044 above the $R^2 = 0.633$ for final quadratic MODEL B-30. The R^2 of MODEL H-11 was 0.024 to 0.036 higher than the R^2-values of the final preliminary models of the MODELS C to G series.

The regression statistics of final MODEL H-11 are shown in Table 25. It had 74 variates including 33 linear, 15 squared, and 26 interaction terms. Most of the interaction and squared variates were

Table 23. Variates included in the multiple regression of yield on management, climatic, and soil variables, MODEL H series

X_i[a]	Variate	X_i	Variate	X_i[a]	Variate
1[b]	YIELD	35	STP2	67	NBDCT*RANGE
		36[c]	PAWC	68	*THAHOR
2	PLDEN				
3	WEEDS	37	$PLDEN^2$	69	RL3*DV
4	NBDCT	38	$NBDCT^2$	70	*PAWC
5	TILE	39	$RL3^2$	71	CRW*PBDCT
6	RL3	40	$CB1^2$	72	*STP1
7	CRW	41	$CB2^2$	73	CB1*CB2
8	SL1	42	$PLDATE^2$	74	*DV
9	CB1	43	$MANURE^2$	75	*PAWC
10	CB2	44	$PBDCT^2$	76	*TWP
11	PLDATE	45	$NCODE^2$	77	MANURE*STP1
		46	$PH1^2$	78	*DV
12	MANURE				
13	PROW	47	STN^2	79	PBDCT*STP1
14	PBDCT	48	$STP1^2$	80	*CPL
15	NCODE	49	DV^2	81	NCODE*STN
16	KCODE	50	$PAWC^2$	82	KCODE*DV
17	NRES1	51	TWP^2	83	NRES1*RANGE
18	SLOPE	52	$RANGE^2$	84	SLOPE*PH1
19	PH1	53	$THAHOR^2$	85	*STN
20	STN	54	$DRAIN^2$	87	*DCAL
21	STP1	55	CPL^2	88	PH1*DPHMIN
22	STK1	56	$DCAL^2$	89	*DCAL
23	DV	57	PLDEN*CB1	90	STN*TWP
24	EXMO	58	*CB2	91	STP1*DV
26	TWP	59	*DV	92	*THAHOR
27	RANGE	60	WEEDS*DV	93	DV*PAWC
28	THAHOR			94	*RANGE
29	DRAIN	61	NBDCT*CB2	95	*DRAIN
30	CPL	62	*MANURE	96	*BIO
31	BIO	63	*NCODE	97	PAWC*TWP
32	PALEO	64	*STN	98	THAHOR*CPL
33	DPHMIN	65	*STK1	99	DRAIN*BIO
34	DCAL	66	*DV	100	DCAL*STP2

[a]X25 was PAWC in inches; X86 was the dummy variate.

[b]YIELD was the dependent variable regressed on 34 linear, 20 squared, and 43 interaction variates.

[c]X36 was PAWC transformed to mm and used for all PAWC variates.

Table 24. Model selection steps, MODEL H series

Model no.	No. of X variates	Model selection steps	R^2
H-1	97	Complete model, all variates listed in Table 23	.680
2 to 4	95 to 89	Deleted nonsignificant (ns) PLDEN*CB1, CB1*TWP, MANURE*DV, PBDCT*CPL, SLOPE*PH1, PH1*DPHMIN, DV*RANGE, and DRAIN*BIO variates stepwise from MODEL H-1	.680 to .679
5 to 7	86 to 80	Deleted ns WEEDS*DV, NBDCT*MANURE, NBDCT*RANGE, CB1*CB2, PBDCT*STP1, NRES1*RANGE, STP1*THAHOR, DV*BIO, and THAHOR*CPL variates stepwise from MODEL H-4	.679 to .677
8	77	Added THAHOR*CPL and deleted ns $MANURE^2$, DV^2, $DCAL^2$, and DPHMIN from MODEL H-7	.678
11	74	Deleted ns CB1*PAWC, $PH1^2$, and CPL^2 from MODEL H-8; this was the final model	.677

highly significant. No interpretation of MODEL H-11 will be given because additional testing of interactions will be done in the next series, the MODEL J series, in which the deleted interaction variates significant at the 10% to 2% level (listed in Table 22) are to be retested.

Summary of selection of interaction variates

Interactions between the management, climatic, and soil variables retained in final MODEL B-30 were selected in the MODELS C to H series of regressions. Not all 703 interactions between the 37 variables in MODEL B-30 and the ALLUV variable could be tested because of limited

Table 25. Regression statistics of yield on selected management, climatic, and soil variates, MODEL H-11[a]

X_i	Variate	b_i	X_i	Variate	b_i
2	PLDEN	0.0897**	44	PBDCT^2	-0.002150*
3	WEEDS	-0.0291**	45	NCODE^2	0.00585*
4	NBDCT	0.1031**	47	STN^2	-0.002487*
5	TILE	0.0670**	48	STP1^2	-0.002408**
6	RL3	0.3714**	50	PAWC^2	0.000512**
7	CRW	-0.1544*	51	TWP^2	-0.00849**
8	SL1	-0.2376**	52	RANGE^2	0.00367*
9	CB1	-0.3817	53	THAHOR^2	-0.001311**
10	CB2	0.3913**	54	DRAIN^2	-0.003962**
11	PLDATE	0.1622			
12	MANURE	0.2520**	58	PLDEN*CB2	-0.000541*
13	PROW	0.0785*	59	*DV	0.02634**
14	PBDCT	0.2261**	61	NBDCT*CB2	-0.00728*
15	NCODE	-1.088**	63	*NCODE	0.001951**
16	KCODE	-0.3202**	64	*STN	-0.000905**
17	NRES1	0.00991^{++}	65	*STK1	-0.0001025**
18	SLOPE	-0.6145^{++}	66	*DV	0.01746*
19	PH1	0.4294**	68	*THAHOR	-0.000630**
20	STN	0.3965*	69	RL3*DV	-0.04401*
21	STP1	0.2108**	70	*PAWC	-0.000615*
22	STK1	0.0176**	71	CRW*PBDCT	-0.00688*
23	DV	11.227**	72	*STP1	-0.00379**
24	EXMO	-1.121**	74	CB1*DV	0.2343**
26	TWP	0.0543	77	MANURE*STP1	-0.00259**
27	RANGE	-0.2571**	81	NCODE*STN	0.00776**
28	THAHOR	0.2996**	82	KCODE*DV	0.09721**
29	DRAIN	0.8223**	85	SLOPE*STN	0.01272**
30	CPL	0.0409	87	*DCAL	-0.00415**
31	BIO	0.7448*	89	PH1*DCAL	-0.00461**
32	PALEO	-5.551**	90	STN*TWP	-0.006048**
34	DCAL	0.0608**	91	STP1*DV	0.03862*
35	STP2	0.00816	93	DV*PAWC	-0.04644**
36	PAWC	-0.0669	95	*DRAIN	-0.1140**
			97	PAWC*TWP	0.001463*
37	PLDEN^2	-0.000155**	98	THAHOR*CPL	-0.004571*
38	NBDCT^2	-0.000285**	100	DCAL*STP2	0.004394**
39	RL3^2	-0.000876*			
40	CB1^2	-0.02187**	--	Intercept	-31.24*
41	CB2^2	-0.002168**	--	R^2	0.677**
42	PLDATE^2	-0.00695**			

[a]YIELD was regressed on 74 variates including 33 linear, 15 squared, and 26 interaction variates.

funds. From the previous research of Henao (1976) and Pena-Olvera (1979) and *a priori* agronomic information, 195 logical interactions were selected to be tested in the MODELS C to G series of regressions. The 60 variates of MODEL B-30 were used as the base set of variates. The 195 interactions were randomly assigned, 39 to each initial model of the MODELS C to G series.

The most significant interactions in each model were selected by backward, stepwise elimination of the least significant variates. Interaction variates significant at the 0.01 to 0.02 level were retained in each final model. This rigid selection was followed to reduce the total number of interactions in final MODELS C to G to 42, which was the number that could be included in the MODEL H series. The 21 interaction variates that were significant at the 0.02 to 0.10 level prior to deletion were selected to be retested in a later model series.

The 42 most significant interactions from final MODELS C to G were then combined and tested in the MODEL H series with the base set of variates from MODEL B-30, except for five linear and squared variates deleted because of nonsignificance in the MODELS C to G series. After a series of stepwise, backward eliminations of nonsignificant variates, MODEL H-11 was selected as the final model. It had 74 variates including 33 linear, 15 squared, and 26 interaction terms. Addition of the interaction variates increased the R^2 of MODEL H-11 to 0.677 from the R^2 of 0.633 for quadratic MODEL B-30.

Selection of the Final Yield Prediction Model

For selection of the final yield prediction model, interaction variates which had significance greater than 2% but less than 10% and had been deleted in the MODELS C to G series (Table 22) were retested in the MODEL J series. All variates retained in MODEL H-11 were included as the base set of variates. This step was taken to determine if each interaction listed in Table 22 would become more important in the presence of the most significant interactions selected in the previous MODELS C to G and MODEL H series. Deletion of 23 variates in final MODEL H-11 provided space to retest all 21 interactions listed in Table 22, the PBDCT*STP1 interaction which was deleted from MODEL H, and the ALLUV variable since it had to be present in the model because two interactions with ALLUV were added.

Regression of yield on quadratic and interaction functions of management, climatic, and soil variables, MODEL J series

Variates included in the MODEL J series are listed in Table 26. All variates in MODEL H-11 were included together with 22 additional interactions and the linear ALLUV variate. Initial MODEL J-1 had 34 linear, 15 squared, and 48 interaction variates.

Model selection The model selection steps for the MODEL J series are given in Table 27. Stepwise, backward elimination of nonsignificant interaction variates was done as before. Variates were retained if significant at the 10% level. A nonsignificant squared term was deleted, but the linear variate was retained regardless of its significance if an interaction or squared variate involving that variable was significant.

Table 26. Variates included in the multiple regression of yield on management, climatic, and soil variables, MODEL J series

X_i^a	Variate	X_i	Variate	X_i^a	Variate
1[b]	YIELD	35	STP2	68	CB2*RANGE
		36[c]	PAWC	69	PLDATE*DV
2	PLDEN			70	*TWP
3	WEEDS	37	$PLDEN^2$	71	MANURE*STP1
4	NBDCT	38	$NBDCT^2$	72	*STK1
5	TILE	39	$RL3^2$	73	PROW*NCODE
6	RL3	40	$CB1^2$	74	*PH1
7	CRW	41	$CB2^2$	75	PBDCT*NRES1
8	SL1	42	$PLDATE^2$	76	*STP1
9	CB1	43	$PBDCT^2$		
10	CB2	44	$NCODE^2$	77	NCODE*STN
11	PLDATE	45	STN^2	78	*STK1
		46	$STP1^2$	79	*DRAIN
12	MANURE	47	TWP^2	80	*DCAL
13	PROW	48	$RANGE^2$	81	KCODE*STK1
14	PBDCT	49	$THAHOR^2$	82	*DV
15	NCODE	50	$DRAIN^2$	83	NRES1*THAHOR
16	KCODE	51	$PAWC^2$	84	SLOPE*STN
17	NRES1			85	*DCAL
18	SLOPE	52	PLDEN*CB2		
19	PH1	53	*DV	87	PH1*TWP
20	STN	54	*THAHOR	88	*BIO
21	STP1	55	NBDCT*CB1	89	*DCAL
22	STK1	56	*CB2	90	STN*TWP
		57	*NCODE	91	*ALLUV
23	DV	58	*STN	92	STP1*DV
24	EXMO	59	*STP1	93	STK1*BIO
26	TWP	60	*STK1		
27	RANGE	61	*DV	94	DV*DRAIN
28	THAHOR	62	*THAHOR	95	*PAWC
29	DRAIN			96	TWP*PAWC
30	CPL	63	RL3*DV	97	THAHOR*CPL
31	BIO	64	*PAWC	98	BIO*STP2
32	PALEO	65	CRW*PBDCT	99	ALLUV*DCAL
33	ALLUV	66	*STP1	100	DCAL*STP2
34	DCAL	67	CB1*DV		

[a]X25 was PAWC in inches; X86 was the dummy variate.

[b]YIELD was the dependent variable regressed on 34 linear, 15 squared, and 48 interaction variates.

[c]X36 was PAWC transformed to mm and used for all PAWC variates.

Table 27. Model selection steps, MODEL J series

Model no.	No. of X variates	Model selection steps	R^2
J- 1	97	Complete model, all variates listed in Table 26	.682
2 to 6	93 to 83	Deleted nonsignificant (ns) PLDEN*THAHOR, NBDCT*CB1, NBDCT*STP1, PROW*NCODE, PROW*PH1, PBDCT*NRES1, PBDCT*STP1, NCODE*STK1, NCODE*DCAL, NRES1*THAHOR, PH1*TWP, PHI*BIO, STN*ALLUV, and ALLUV*DCAL variates stepwise from MODEL J-1	.682 to .681
7 to 9	82 to 81	Added PBDCT*NRES1 and deleted ns CRW*PBDCT, PLDATE*DV, and ALLUV variates stepwise from MODEL J-6	.681 to .681
10	80	Deleted ns $RANGE^2$ variate from MODEL J-9; this was selected to be the final model	.681

The complete model, with all variates listed in Table 26, had an $R^2 = 0.682$. Fourteen interaction variates were deleted as the model selection steps proceeded from MODEL J-2 to MODEL J-6 (Table 27). The R^2 decreased from 0.682 to 0.681. Because all variates involving ALLUV were deleted, the nonsignificant linear ALLUV was then deleted in MODEL J-7. In MODELS J-8 and J-9, two more interactions were deleted and the PBDCT*NRES1 interaction, which was deleted in a previous step, was replaced in the model.

In MODEL J-10, the nonsignificant $RANGE^2$ variate was deleted. MODEL J-10 with all of its interaction and squared variates significant at least at the 10% level was then selected as the final model in this study. The R^2 of 0.681 for MODEL J-10 was slightly higher than the R^2

of 0.677 for MODEL H-11. There was only a slight gain in retesting several interactions and retaining a few that had been deleted previously. The analysis of variance of the final yield prediction model, MODEL J-10, is given in Appendix Table A11.

Interpretation of final prediction MODEL J-10 The regression statistics of the final interaction yield prediction model, MODEL J-10, are given in Table 28. It had 80 variates including 33 linear, 14 squared, and 33 interaction variates; 51 variates were significant at the 1% level, 20 were significant at the 5% level, and 4 were significant at the 10% level.

The variable effects on yield, including the interactions each variable had on yield, in final MODEL J-10 are summarized in Table 29. The moisture stress index, DV, was involved in the largest number of interactions with other variables. Of its 8 interactions, 6 were with management variables and only 2 were with soil variables.

The NBDCT variable had the next largest number of interactions; it had 6 interactions, 5 with management variables, and only 1 with a soil variable. Both STN and STK1 variables had 4 interactions in the model. Six variables (CB2, NCODE, STP1, TWP, DCAL, and PAWC) had 3 interactions each with other variables. Nine variables (PLDEN, RL3, MANURE, KCODE, SLOPE, THAHOR, DRAIN, BIO, and STP2) had 2 interactions each, while 8 other variables (CRW, CB1, PLDATE, PBDCT, NRES1, PH1, RANGE, and CPL) each had only 1 interaction with another variable.

Six variables (WEEDS, TILE, SL1, PROW, EXMO, and PALEO) had only a linear effect and no interaction effects on yield. Their effects on

Table 28. Regression statistics of the final model of yield on selected management, climatic, and soil variates, MODEL J-10

X_i	Variate[a]	b_i	X_i	Variate	b_i
2	PLDEN (360;193-751)	0.08474**	45	STN^2	-0.002088*
3	WEEDS (58;0-475)	-0.02913**	46	STP1^2	-0.002401**
4	NBDCT (56;0-336)	0.1023**	47	TWP^2	-0.008926**
5	TILE (6;0-61)	0.0701**	49	THAHOR^2	-0.001295**
6	RL3 (10;0-99)	0.4042**	50	DRAIN^2	-0.003502**
7	CRW (15;10-54)	-0.1972**	51	PAWC^2	0.0005085**
8	SL1 (4;0-84)	-0.2397**			
9	CB1 (3;0-38)	-0.4120	52	PLDEN*CB2	-0.0004753*
10	CB2 (14;0-99)	0.3053**	53	*DV	0.02725**
11	PLDATE (24;0-56)	0.2915*	56	NBDCT*CB2	-0.0008072**
12	MANURE (5;0-67)	0.3163**	57	*NCODE	0.001993**
13	PROW (8;0-47)	0.07177*	58	*STN	-0.0008789**
14	PBDCT (8;0-98)	0.1253**	60	*STK1	-0.0001575**
15	NCODE (23;8-40)	-1.0003**	61	*DV	0.01837*
16	KCODE (18;0-60)	-0.2400**	62	*THAHOR	-0.0005881**
17	NRES1 (36;0-336)	0.01394*	63	RL3*DV	-0.04926*
18	SLOPE (4;0-21)	-0.7761*	64	*PAWC	-0.0006723*
19	PH1 (15;1-32)	0.4366**	66	CRW*STP1	-0.004674**
20	STN (65;24-100)	0.3137*	67	CB1*DV	0.2413**
21	STP1 (31;5-100)	0.2278**	68	CB2*RANGE	0.002820*
22	STK1 (209;35-400)	0.6020**	70	PLDATE*TWP	-0.005950*
23	DV (3.8;1.1-5.2)	11.244**	71	MANURE*STP1	-0.001748*
24	EXMO (1.3;0-14.8)	-1.158**	72	*STK1	-0.0003978^{++}
26	TWP (20;2-34)	0.09378	75	PBDCT*NRES1	-0.0005293*
27	RANGE (26;0-48)	-0.1219**	77	NCODE*STN	0.008471**
28	THAHOR (36;0-99)	0.3113**	79	*DRAIN	-0.002200^{++}
29	DRAIN (44;10-90)	0.8151**	81	KCODE*STK1	-0.0004105**
30	CPL (26;5-58)	0.08589	82	*DV	0.09576**
31	BIO (4.7;1-5)	0.7074	84	SLOPE*STN	0.01475**
32	PALEO (-;0-1)	-5.213**	85	*DCAL	-0.003793**
34	DCAL (31;0-137)	0.06268**	89	PH1*DCAL	-0.004474**
35	STP2 (18;5-98)	-0.07543^{++}	90	STN*TWP	-0.006000**
36	PAWC (249;64-311)	-0.06560	92	STP1*DV	0.03592*
			93	STK1*BIO	-0.006430*
37	PLDEN^2	-0.0001544**	94	DV*DRAIN	-0.1132**
38	NBDCT^2	-0.0002484**	95	*PAWC	-0.04800**
39	RL3^2	-0.0008453*	96	TWP*PAWC	0.002022**
40	CB1^2	-0.02190**	97	THAHOR*CPL	-0.005166*
41	CB2^2	-0.002562**	98	BIO*STP2	0.02340*
42	PLDATE^2	-0.007204**	100	DCAL*STP2	0.004019**
43	PBDCT^2	-0.001469^{++}	--	Intercept	-33.65*
44	NCODE^2	0.005328*	--	R^2	0.681**

[a]Rounded means and ranges of the variables are given in the parentheses.

Table 29. Summary of the variable effects on corn yield in final MODEL J-10

Variable	t-values		Interacting variable with listed significance and its sign and significance level
	Linear	Squared	
PLDEN	3.2**	-7.5**	-CB2*, +DV**
WEEDS	-9.5**	ns	None
NBDCT	2.7**	-4.6**	-CB2**, +NCODE**, -STN**, -STK1**, +DV*, -THAHOR**
TILE	4.2**	ns	None
RL3	4.3**	-2.1*	-DV*, -PAWC*
CRW	-3.2**	ns	-STP1**
SL1	-6.5**	ns	None
CB1	-1.4	-4.2**	+DV**
CB2	3.4**	-4.3**	-PLDEN*, -NBDCT**, +RANGE*
PLDATE	2.0*	-3.2**	-TWP*
MANURE	5.8**	ns	-STP1*, -STK1++
PROW	2.3*	ns	None
PBDCT	3.0**	-1.6++	-NRES1*
NCODE	-5.9**	2.1*	+NBDCT**, +STN**, -DRAIN++
KCODE	-2.6**	ns	-STK1**, +DV**
NRES1	2.3*	ns	-PBDCT*
SLOPE	-2.4*	ns	+STN**, -DCAL**
PH1	8.3**	ns	-DCAL**
STN	2.0*	-2.0*	-NBDCT**, +NCODE**, +SLOPE**, -TWP**
STP1	2.9**	-5.8**	-CRW**, -MANURE*, +DV*
STK1	3.7**	ns	-NBDCT**, -MANURE++, -KCODE**, -BIO*
DV	3.7**	ns	+PLDEN**, +NBDCT*, -RL3*, +CB1**, +KCODE**, +STP1*, -DRAIN**, -PAWC**
EXMO	-8.6**	ns	None
TWP	0.4	-.27**	-PLDATE*, -STN**, +PAWC**
RANGE	-3.8**	ns	+CB2*
THAHOR	3.6**	-2.7**	-NBDCT**, -CPL*
DRAIN	5.8**	-3.3**	-NCODE++, -DV**
CPL	0.9	ns	-THAHOR*
BIO	1.1	ns	-STK1*, +STP2*
PALEO	-3.3**	--	None
DCAL	3.3**	ns	-SLOPE**, -PH1**, +STP2**
STP2	-1.8++	ns	+BIO*, +DCAL**
PAWC	-1.2	4.6**	-RL3*, -DV**, +TWP**

yield in MODEL J-10 were almost identical with those shown in the final quadratic MODEL B-30. Their effects were discussed in the MODEL A or MODEL B series section and will not be discussed in this section.

The effects of the other variables that had interactions on yield will be discussed in the following subsections. The various methods to determine the interaction effects on yield will be discussed in the PLDEN subsection.

PLDEN The PLDEN (plant density) variable had a quadratic effect on corn yield modified by interactions with CB2 and DV (Table 29). A PLDEN*NBDCT interaction was expected, but it was not significant, probably because of the high correlation of $r = 0.58$ between these two variables.

Information about the effect of a variable on yield in the multiple regression equation can be obtained by taking the partial derivative of yield with respect to the variable. For example, the partial derivative of YIELD with respect to PLDEN, from the regression statistics in Table 28, is: dYIELD/dPLDEN = 0.08474 - 0.0003088 PLDEN - 0.0004753 CB2 + 0.02725 DV. The partial derivative shows that the slope of the yield response on PLDEN level (change in YIELD per unit change in PLDEN) is affected by the levels of CB2 and DV. At CB2 = 10, the simplified derivative = 0.07999 - 0.0003088 PLDEN + 0.02725 DV. If DV values of 1 to 5 (severe to no moisture stress) are substituted into the simplified derivative and the equation set equal to 0, the PLDEN values associated with YMAX (maximum yield) can be computed. The decoded PLDEN values that gave YMAX at DV = 1 to 5 were 34,730, 43,550, 52,380, 61,200, and 70,020 plants/ha, respectively. This effect of moisture stress on the plant density associated with YMAX has been reported frequently.

If DV is set = 4 (slight moisture stress), the simplified derivative in terms of PLDEN and CB2 = 0.19374 - 0.0003088 PLDEN - 0.0004753 CB2. As CB2 varied from 0 to 60, the decoded PLDEN that gave YMAX thus decreased from 62,700 to 53,500 plants/ha.

Another method used to show the effects of interactions in the regression equation on yield is to fix all other variables at constant values except the 2 or 3 variables to be studied. From the resulting simplified yield equation, yields can be computed and plotted to illustrate the interaction effects. To determine the effect of the PLDEN*DV interaction on yield, all other variables were fixed at constant values and the products of these values and their respective regression coefficients in the linear, squared, and interaction variates were added to the intercept or to the linear coefficients for PLDEN or DV. By setting all other variables constant at their mean values listed in Table 28, the simplified equation was: YIELD = 34.95 + 0.07808 PLDEN - 0.0001544 PLDEN^2 - 1.592 DV + 0.02725 PLDEN*DV. The effects of PLDEN and DV levels on YIELD are shown in Figure 8. As moisture stress decreased (from DV = 1 to 5), YIELD increased and the effect of PLDEN on YIELD increased. The PLDEN values that gave YMAX are connected by the curved dashed line in Figure 8; these values were also computed from the partial derivative of YIELD with respect to PLDEN, as discussed previously.

If the values of the other variables are set at different levels,

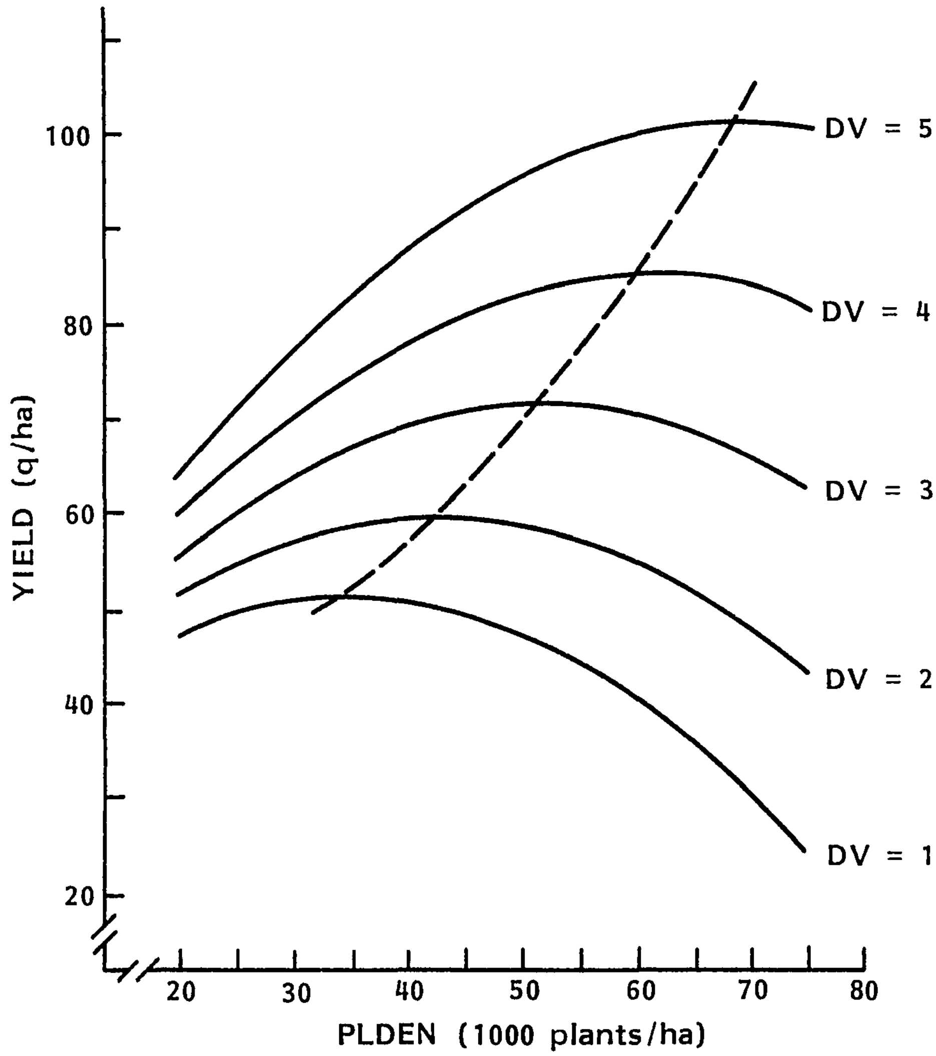


Figure 8. Estimated corn yields at different plant density (PLDEN) and moisture stress index (DV) levels (maximum yields are connected by the dashed line)

the yield curves shown in Figure 8 change in elevation or the relationship between PLDEN and DV on YIELD changes if levels of the variables which have interactions with PLDEN or DV are changed. The effects of the interacting variables on yield can be shown by this method but the available programming was laborious for computer calculations.

Another method to illustrate the interaction effects between or among 2 or 3 variables on yield is to compute changes in yield (ΔYIELD) from a simplified ΔYIELD equation. The ΔYIELD equation for the PLDEN, CB2, and DV variables included all linear, squared, and interaction variates of these three variables. All variables not interacting with these three variables were set equal to zero. All variables interacting with the PLDEN, CB2, and DV variables were set at constant values and the terms involving the linear CB2 and DV variates were collected (added together). The resulting ΔYIELD equation included quadratic functions of PLDEN and CB2, the linear function of DV, and the interactions between PLDEN and both CB2 and DV.

The ΔYIELD values were then computed for combinations of various levels of PLDEN, CB2, and DV. A computer program was written to compute these values for given levels of the three variables. The computed ΔYIELD value for PLDEN = 200, CB2 = 0, and DV = 2 (the minimum levels of the three variables in the example) was set = 0 by subtracting the computed value. All other ΔYIELD values were then adjusted by subtracting this constant. Thus, all ΔYIELD values were set relative to 0 for the minimum value of each of the three variables. This step is not necessary if minimum levels of all variables are 0. This method will be used to explain the interaction effects of these and all other variables on yield because it is simpler to program for computer calculations.

The effects of PLDEN on YIELD at selected levels of CB2 and DV are shown in Figure 9. The variables interacting with DV and CB2 were set at the following levels: NBDCT = 180, CB1 = 5, RL3 = 0, KCODE = 5, STP1 = 35, RANGE = 20, DRAIN = 40, and PAWC = 280. All are in units as listed in Tables 5 and 12. The positive interaction between PLDEN and DV on ΔYIELD was similar to that shown on YIELD in Figure 8 at a fixed CB2 level of 14.

The negative interaction between PLDEN and CB2 on ΔYIELD in Figure 9 showed that the yield response to increasing PLDEN level decreased as the CB2 level increased. The PLDEN level associated with maximum ΔYIELD also decreased as the second-brood corn borer level increased. This was shown previously in the analysis of the partial derivative of YIELD with respect to PLDEN. The effects of the interaction between PLDEN and CB2 on ΔYIELD were the same at all DV levels because no significant interaction between DV and CB2 on YIELD occurred in MODEL J-10. The differential yield responses to CB2 levels at various PLDEN levels will be discussed in the CB2 subsection.

The relationship between PLDEN, CB2, and DV on ΔYIELD shown in Figure 9 will change somewhat if the levels of the variables interacting with CB2 or DV are changed. For example, changing the levels of the NBDCT and RANGE variables which interacted with CB2 will change the regression coefficient of the linear CB2 variate in the simplified

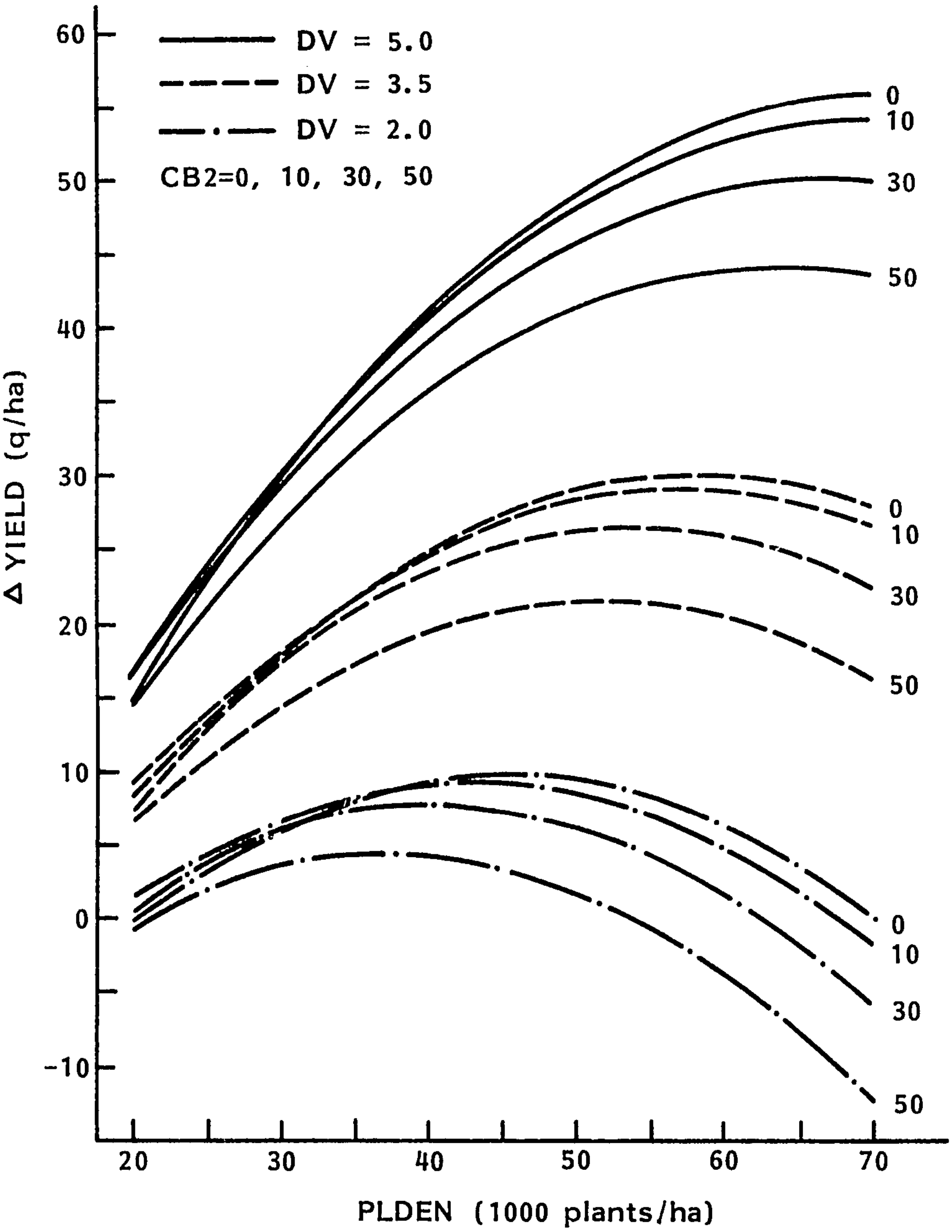


Figure 9. Change in yield (ΔYIELD) with plant density (PLDEN) levels at different second brood corn borer infestation (CB2) and moisture stress index (DV) levels

equation and, therefore, the yield response curves.

NBDCT The N fertilizer application other than row (NBDCT) variable had a quadratic effect on corn yield modified by six interactions with CB2, NCODE, STN, STK1, DV, and THAHOR (Tables 28 and 29). Interactions between NBDCT and PLDEN ($r = 0.58$) and NBDCT and PBDCT ($r = 0.49$) were also expected, but they were not significant, probably because NBDCT was highly correlated with both. The positive interactions showed that the yield response to NBDCT increased as NCODE increased (from 1st-year to 4th-year corn after meadow) and as coded DV increased (from severe to no moisture stress). The negative interactions showed that the NBDCT effect on yield decreased as CB2, STN, STK1, and THAHOR levels increased. All of these interactions except the one with STK1 were in the expected direction.

The effect of the NBDCT*DV interaction on ΔYIELD due to NBDCT levels is shown in Figure 10. The ΔYIELD equation was simplified by setting CB2 = 10, NCODE = 30, STN = 50, STK1 = 200, THAHOR = 25, PLDEN = 600, RL3 = 0, CB1 = 2, KCODE = 10, STP1 = 35, DRAIN = 40, and PAWC = 280 (units listed in Tables 5 and 12). All of these variables had interactions with NBDCT or DV. The simplified equation then was: $\Delta YIELD = 0.0610\ NBDCT + 12.29\ DV - 0.0002484\ NBDCT^2 + 0.01837\ NBDCT*DV$. The computed value of ΔYIELD at NBDCT = 0 and DV = 1 was adjusted to 0 and all other ΔYIELD values were adjusted accordingly.

The effect of NBDCT levels on ΔYIELD varied with DV level (which had the dominant effect on ΔYIELD). With severe moisture stress (DV=1), a low ΔYIELD (about 7 q/ha) occurred as NBDCT increased from 0 to 160

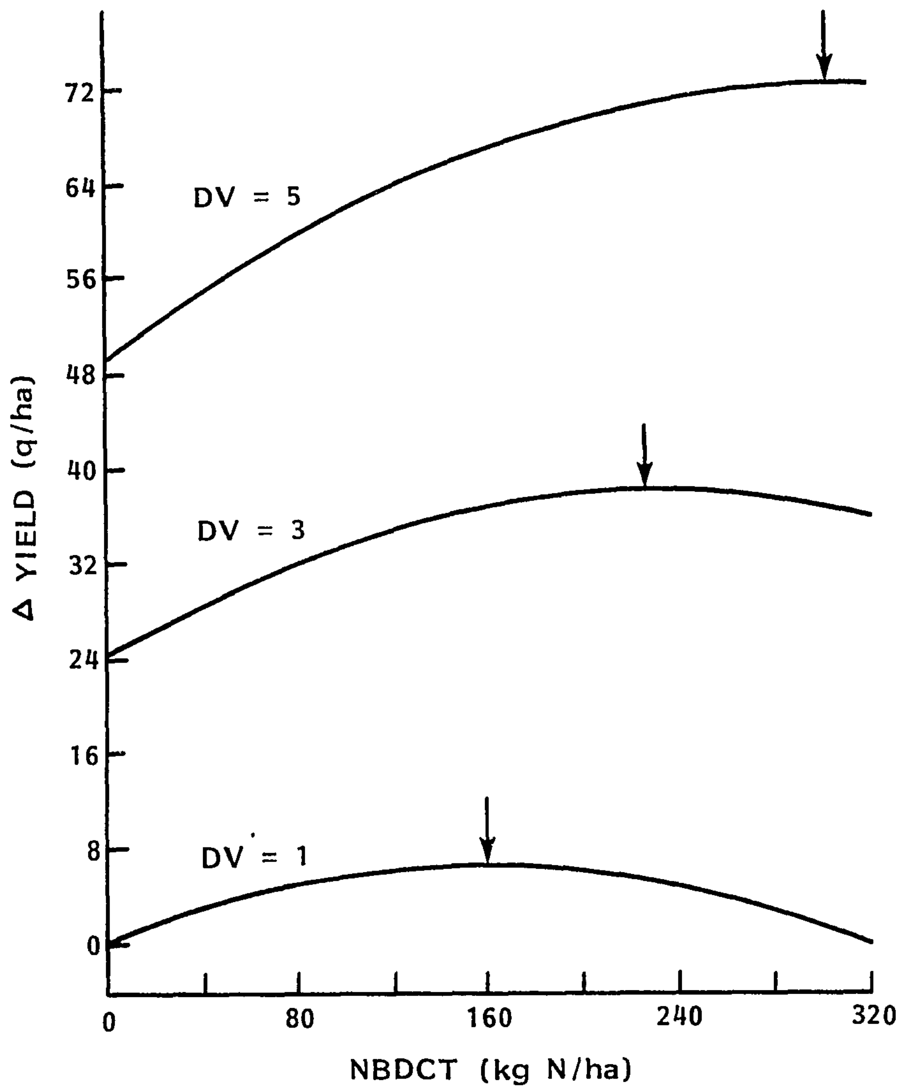


Figure 10. Change in yield (ΔYIELD) with N fertilizer other than row application (NBDCT) at different moisture stress index (DV) levels (arrows show points of maximum ΔYIELD)

kg N/ha which gave the maximum ΔYIELD (ΔYMAX). With moderate stress (DV=3), ΔYIELD was greater and ΔYMAX (about 14 q/ha) occurred at 234 kg N/ha. With no stress (DV=5), the ΔYIELD to NBDCT was even higher and ΔYMAX (about 23 q/ha or 37 bu/acre) occurred at 308 kg N/ha (275 lb N/acre). The greater yield response to N at low or no moisture stress was expected, but the ΔYIELDS were less and NBDCT levels at ΔYMAX values were greater than expected.

The effects of the interrelated interactions of NBDCT, NCODE, and STN on ΔYIELD are shown in Figure 11. Interacting variables with these three variables were fixed as follows: CB2 = 10, STK1 = 200, DV = 4, THAHOR = 30, DRAIN = 40, SLOPE = 5, and coded TWP = 15. The ΔYIELD values for selected combinations of NBDCT, NCODE, and STN levels were then computed and plotted. As shown in Figure 11, the interaction between NBDCT and NCODE can be examined at each level of STN; the NBDCT*STN interaction can be examined at each level of NCODE; and the NCODE*STN interaction on ΔYIELD can be examined at each level of NBDCT.

The yield responses (ΔYIELD) to NBDCT levels were least for 1st-year corn (NCODE=10) and largest for 4th-year corn (NCODE-40); the NBDCT level that gave ΔYMAX also increased as NCODE varied from 10 to 40. Most of the interaction effect between NBDCT and NCODE was due to the yield decrease of 4th-year corn compared to 1st-year corn which was largest at NBDCT = 0 (Figure 11).

Yield responses to NBDCT levels were also influenced by STN levels. Response to N was larger at the very low to low soil test N level (STN=40) than at the medium-high level (STN=80); the ΔYMAX also occurred at

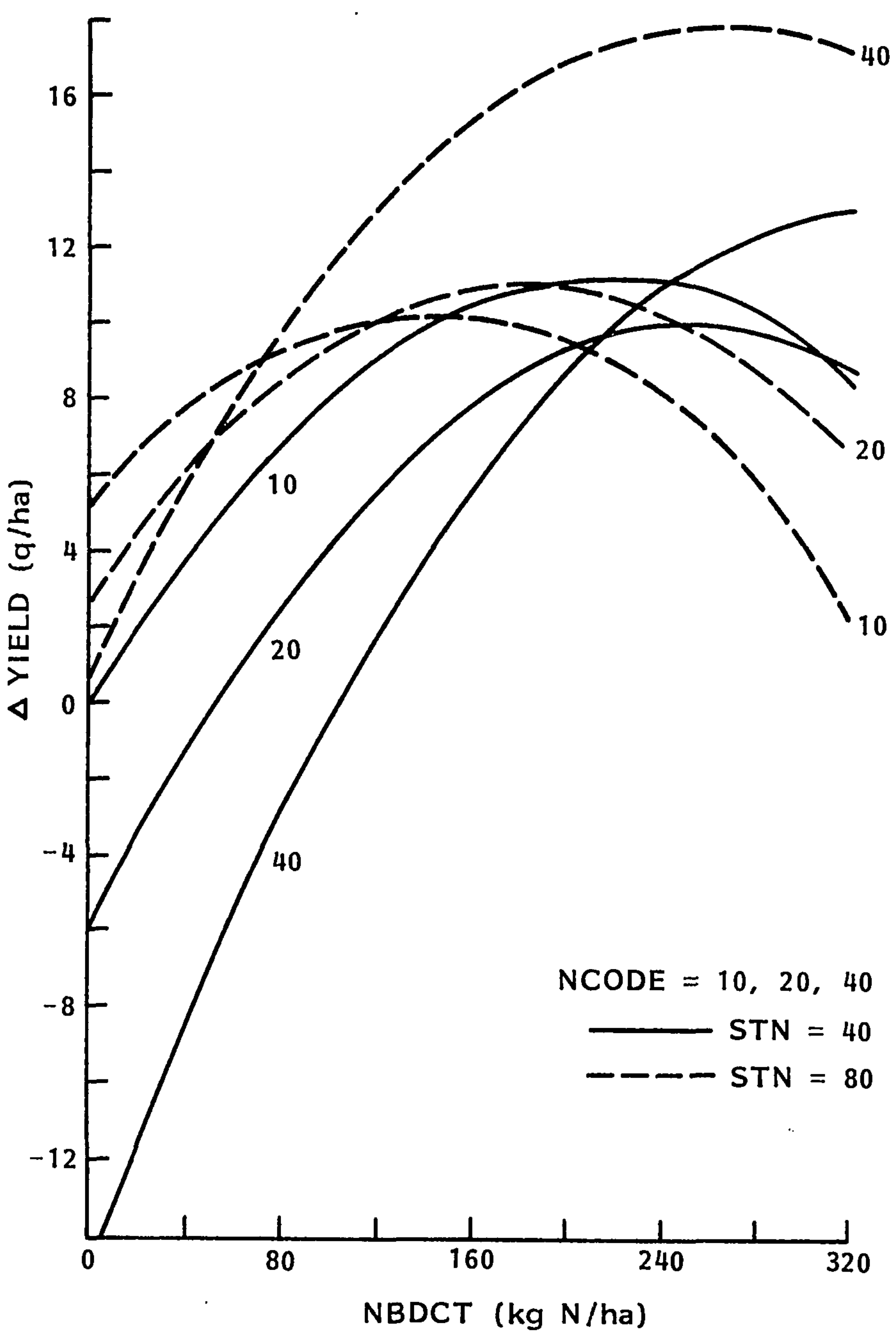


Figure 11. Change in yield (ΔYIELD) with N fertilizer other than row application (NBDCT) at different crop sequence (NCODE) and soil test N in the plow layer (STN) levels

higher levels of NBDCT at the lower than the higher STN level at all NCODE levels. Because of the significant interactions among all three variables, the maximum yield response to NBDCT occurred at the low STN level and 4th-year corn (NCODE=40). The obvious effects of NCODE and STN on ΔYIELD in Figure 11 will be discussed later in their subsections.

The effects of the negative interactions between NBDCT and CB2, STK1, and THAHOR on YIELD were examined from the simplified partial derivative of dYIELD/dNBDCT which, at NCODE = 30, STN = 50, and DV = 4, is: 0.192 - 0.000497 NBDCT - 0.000807 CB2 - 0.000158 STK1 - 0.000588 THAHOR. This equation shows that the initial slopes of the yield response function at NBDCT = 0, the yield responses to NBDCT, and the NBDCT levels at YMAX decrease with increasing CB2, STK1, and THAHOR levels. The effects of NBDCT levels on yield responses to CB2, STK1, and THAHOR levels will be discussed later in their subsections.

The complex relationships between the interacting variables of NBDCT, NCODE, and STN on ΔYIELD as shown in Figure 11 will change if the levels of the other interacting variables are changed. The examples shown illustrate the general relationships.

RL3 The RL3 (total root lodging) variable had a quadratic effect on yield and negative interactions with DV and PAWC (Tables 28 and 29). The dYIELD/dRL3 = 0.404 - 0.00169 RL3 - 0.0493 DV - 0.000672 PAWC. At DV = 4, the simplified derivative = 0.207 - 0.00169 RL3 - 0.000672 PAWC. At PAWC = 100, 200, and 300 mm/1.5 m (3.9 to 11.8 in./5 ft), YMAX occurred at 83, 43, and 3% root lodging, respectively. The effect at the lower PAWC values appears unrealistic. Little root lodging occurred, however, on the sandy soils which had low PAWC values; thus, the estimated effects at the lower PAWC values were outside of the range of the observed values. At the average PAWC = 250, YMAX occurred at RL3 = 23%; as root lodging increased from 23% to 100%, the yield was decreased about 5 q/ha (8 bu/acre). This effect was similar to that found in quadratic MODEL A-35 (Figure 3A).

At PAWC = 250, the simplified derivative = 0.236 - 0.00169 RL3 - 0.0493 DV. As DV increased from 2 to 4, YMAX occurred at 81 to 23% root lodging. At DV = 5, the yield decreased throughout the root lodging range; from 0 to 100% root lodging, yield decreased 9 q/ha (14 bu/acre). The effects of both DV and PAWC on the yield response to RL3 levels were similar.

<u>CRW</u> The dYIELD/dCRW = -0.197 - 0.00467 STP1. As STP1 increased from 10 to 60 pp2m, the slope of the linear yield response on CRW (root damage rating due to corn rootworm) changed from -0.244 to -0.477. From CRW = 10 (none) to 50 (severe), the yield decreased 10 q/ha (16 bu/acre) at STP1 = 10 (very low soil test P) and 19 q/ha (30 bu/acre) at STP1 = 60 (high). A similar relationship between CRW and STP1 on corn yield was reported by Turpin et al. (1972).

<u>CB1</u> The curvilinear effect of CB1 (first-brood corn borer infestation) on corn yield was modified by DV. The dYIELD/dCB1 = -0.412 - 0.0438 CB1 + 0.241 DV. At severe stress (DV=1), the ΔYIELD decreased at an increasng rate as CB1 increased.

With better soil moisture conditions, the effect of CB1 became less detrimental and then positive at lower infestation levels. From

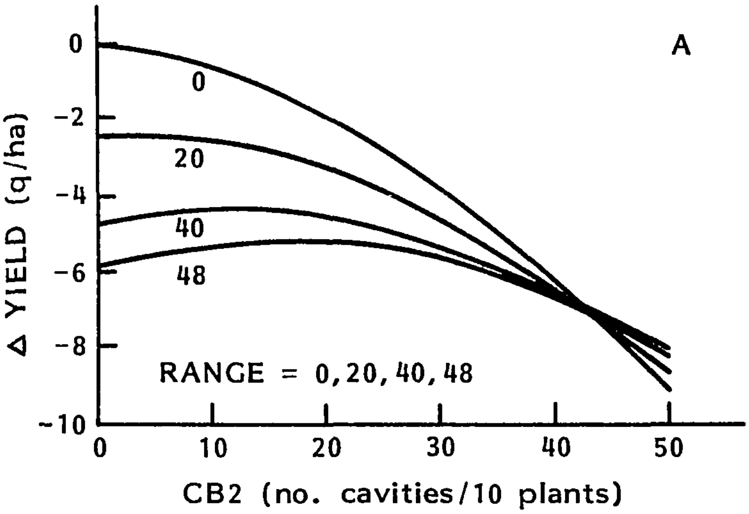
DV = 2 to DV = 5, YMAX occurred at about 2 to 18 cavities/10 plants. At the average DV = 3.8, YMAX occurred at 11.5 cavities/10 plants. These effects were similar to the effects of CB1 in quadratic MODELS A-35 and B-30; in both models, YMAX occurred at CB1 = 9.5 cavities/10 plants. Possible reasons for this unexpected effect of CB1 on yield were discussed previously in the MODEL A series section.

CB2 The second-brood corn borer (CB2) variable had a curvilinear effect on YIELD in MODEL J-10 modified by negative interactions with PLDEN and NBDCT and a positive interaction with RANGE. The partial derivative was dYIELD/dCB2 = 0.305 - 0.00512 CB2 - 0.000475 PLDEN - 0.000807 NBDCT + 0.00282 RANGE.

The interaction between CB2 and PLDEN is shown in Figure 9. At a very low decoded PLDEN level of 20,000 plants/ha, ΔYIELD increased as CB2 increased to about 15 cavities/10 plants and then decreased at higher CB2 levels. Above about 35,000 plants/ha (14,000 plants/acre), ΔYIELD decreased at an increasing rate at all CB2 levels.

At coded PLDEN = 500 and RANGE = 26 (mean value), the simplified derivative = 0.141 - 0.00512 CB2 - 0.000807 NBDCT. At NBDCT = 0, YMAX occurred at CB2 = 29 cavities/10 plants; at NBDCT = 175, YMAX occurred at CB2 = 0 and yield decreased at an increasing rate as CB2 level increased. Increasing CB2 levels had an increasingly detrimental effect on corn yield as PLDEN and NBDCT levels increased.

The effect of the RANGE variable (E-W location) on ΔYIELD to an increasing CB2 level is shown in Figure 12A. For computing the ΔYIELDS, PLDEN and NBDCT levels were set at 500 plants/0.01 ha and 150 kg N/ha,



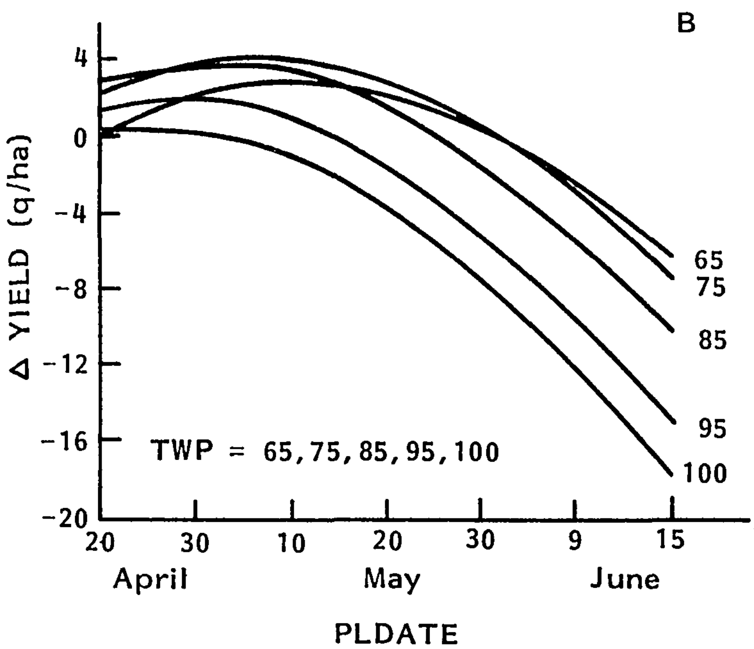


Figure 12. Change in yield (ΔYIELD) with (A) second brood corn borer infestation (CB2) levels at various E-W locations (RANGE) in Iowa, and (B) planting date (decoded PLDATE) at various S-N locations (decoded TWP) in Iowa

respectively. Increasing CB2 level had a larger negative effect on yields in eastern Iowa (RANGE = 0 to 20) than in western Iowa (RANGE = 40 to 48).

The simplified derivative at the given PLDEN and NBDCT levels = -0.0534 - 0.00512 CB2 + 0.00282 RANGE. For RANGE = 20, 40, and 48, YMAX occurred at CB2 = 0.6, 11.6, and 16.0 cavities/10 plants, respectively. These are very light to light second-brood corn borer infestations. At RANGE = 40, ΔYIELD was 0.3 q/ha as CB2 increased from 0 to 11.6 but was -3.8 q/ha (-6 bu/acre) as CB2 increased from 11.6 to 50 cavities/10 plants (Figure 12A). The negative effects of CB2 on yield were larger in the interaction models at relevant PLDEN and NBDCT levels than in the quadratic models in which the CB2 effects were estimated at the low mean levels of PLDEN and NBDCT.

PLDATE The PLDATE (planting date) variable had a curvilinear effect on YIELD in MODEL J-10 modified by TWP (S-N location in Iowa). The dYIELD/dPLDATE = 0.292 - 0.0144 PLDATE - 0.00595 TWP. The interaction between PLDATE and TWP on ΔYIELD is illustrated in Figure 12B. The PLDATE associated with ΔYMAX decreased (became earlier) from southern to northern Iowa. The decoded planting dates associated with ΔYMAX were May 10, May 6, May 2, April 28, and April 26 for decoded TWP 65, 75, 85, 95, and 100, respectively. Delay of the planting date from the date associated with ΔYMAX to June 15 decreased yield from 9 q/ha (14 bu/acre) in decoded TWP65 to 18 q/ha (29 bu/acre) in decoded TWP100 (northern edge of Iowa).

<u>MANURE</u> The MANURE variable in the final prediction model (Tables 28 and 29) had a linear effect on YIELD modified by negative interactions with STP1 and STK1. The dYIELD/dMANURE = 0.316 - 0.00175 STP1 - 0.000398 STK1. The yield response to manure application decreased as the STP1 and STK1 levels increased, as would be expected.

At STP1 = 20 pp2m (low) and STK1 = 100 pp2m (low), the slope of the linear yield response to MANURE = 0.241 q/ha per 1 MT of manure. If the soil test levels are doubled, the slope = 0.166. The yield responses to 22 MT/ha (10 T/acre) of manure thus were 5.3 and 3.6 q/ha (8.4 and 5.7 bu/acre), respectively. These responses were above those from the fertilizer applied at the sites; no significant interactions between manure and fertilizer nutrients occurred.

<u>PBDCT</u> The PBDCT (P fertilizer other than row) variable had a curvilinear effect on YIELD in MODEL J-10 modified by a negative interaction with NRES1 (Tables 28 and 29). Because of the high correlation between NRES1 and PRES1 (r=0.80), the negative interaction in the model was probably between PBDCT and PRES1, primarily.

The dYIELD/dPBDCT = 0.125 - 0.00294 PBDCT - 0.000529 NRES1. The PBDCT levels associated with YMAX decreased as NRES1 levels increased; these were 42.6, 24.6 and 6.6 kg P/ha for NRES1 levels of 0, 100, and 200 kg N/ha, respectively. At NRES1 = 0, the ΔYIELD from 42.6 kg P/ha (87 lb P_2O_5/acre) was only 2.7 q/ha, a very low efficiency of fertilizer P. This response, however, was averaged over all STP1 levels because the PBDCT*STP1 interaction was not significant. Henao (1976) had reported a highly significant interaction between total P from all sources and STP1.

NCODE The crop rotation code for N availability (NCODE) in MODEL J-10 (Table 28) had a curvilinear effect on YIELD modified by positive interactions with NBDCT and STN and a negative interaction with DRAIN. The dYIELD/dNCODE = -1.0003 + 0.01066 NCODE + 0.00199 NBDCT + 0.00847 STN - 0.00220 DRAIN.

At constant NBDCT and STN levels, an increase in coded DRAIN increased the negative yield response to NCODE. With NBDCT = 160 kg N/ha and STN = 50 pp2m, the simplified dYIELD/dNCODE = -0.258 + 0.0107 NCODE - 0.00220 DRAIN. At DRAIN = 30, 50, and 70 (well, somewhat poor, and poor, respectively), YMIN occurred at NCODE = 30.4, 34.5, and 38.6, respectively. The ΔYIELD values from NCODE = 10 to the NCODE associated with YMIN (computed from average slope between the two points on the curve * ΔNCODE) thus were -2.2, -3.3, and -4.4 q/ha (-3.5, -5.3, and -7.0 bu/acre) on the well-, somewhat poorly, and poorly-drained soils, respectively. The negative effect of NCODE (from 1st- to 4th-year corn) thus increased as drainage became poorer.

The interaction effects between NCODE and NBDCT, NCODE and STN, and NBDCT and STN on ΔYIELD from NBDCT levels were shown in Figure 11. The effects of NCODE on ΔYIELD at different NBDCT and STN levels are shown in Figure 13. These response curves were plotted from the same data that were used for Figure 11. The interrelated interaction effects of NCODE, NBDCT, and STN are illustrated from a different perspective. DRAIN was held constant at DRAIN = 40.

At STN = 40 (very low to low), increasing NCODE (from 1st-year to

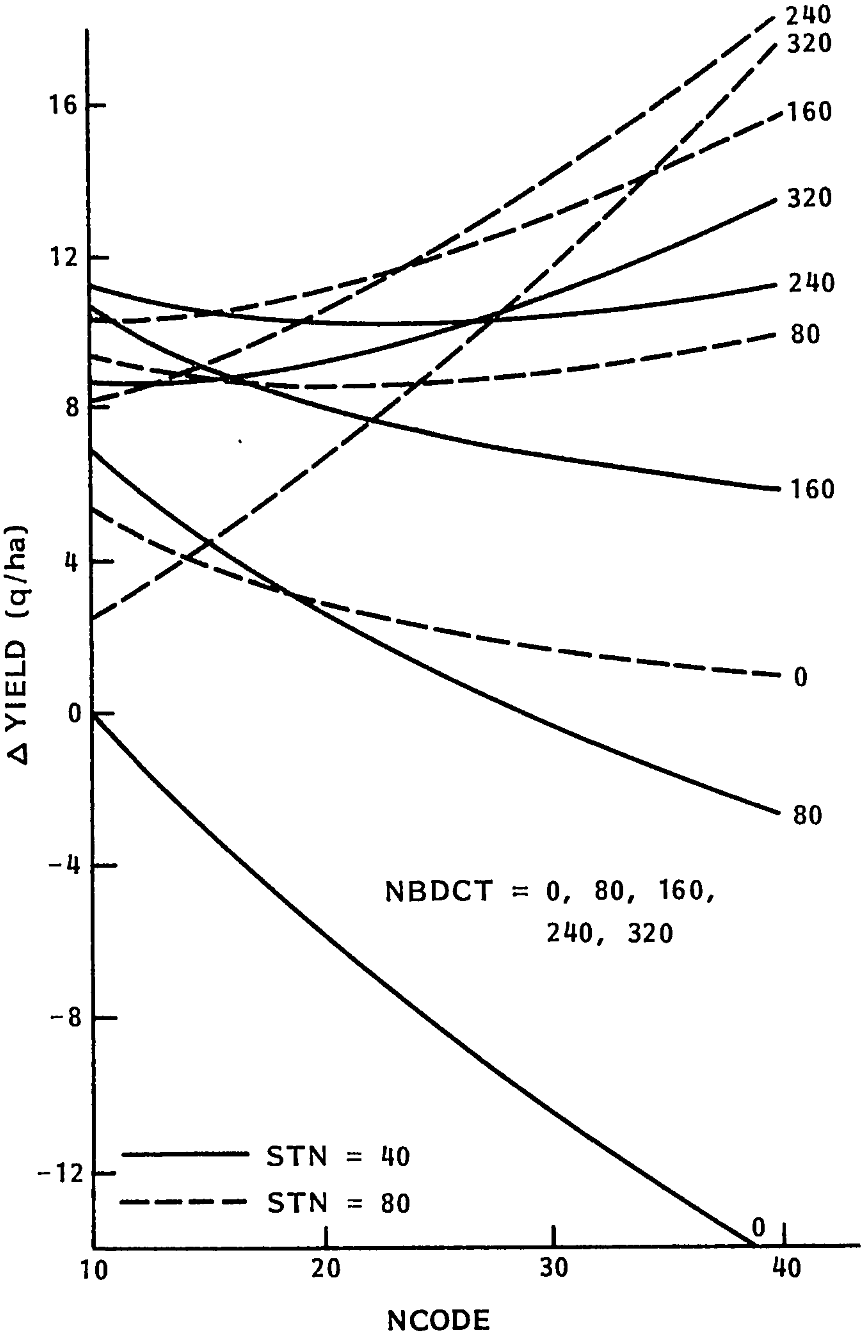


Figure 13. Change in yield (ΔYIELD) with crop sequence (NCODE) at different N fertilizer (NBDCT) and soil test N (STN) levels

4th-year corn) decreased yield markedly at NBDCT = 0 (Figure 13). The negative responses became less with increasing NBDCT level up to 240 kg N/ha where the responses to NCODE levels were almost 0. At STN = 80 (medium-high), the negative effects of NCODE were less than those at STN = 40 and at NBDCT = 0. Responses to NCODE were almost 0 at NBDCT = 80 and then were positive at higher NBDCT levels. Part of these apparent positive responses to NCODE levels were due to the negative ΔYIELD values at the higher NBDCT levels at NCODE 10 and 20. These yield decreases may be due to increased moisture stress and nutrient imbalance from high N rates on 1st-year corn or they may be primarily extrapolated effects because of very few observations having high N rates on 1st-year corn.

The higher yields of 4th-year corn than of 1st-year corn at high NBDCT and STN levels differ from the results of Shrader and Voss (1980). They reported that yields of continuous corn generally were less than those of 1st-year corn after meadow even at high N fertilizer levels. For the coding of NCODE, the effect of the soybean crop in the crop sequence was considered only for its effect on N availability (Appendix Table A2). It appears that the crop sequence effect should be recoded before further regression analyses. Other factors affecting comparisons of the results from this research and others are that the CRW damage rating was constant (no interactions with the available N variables) and that these data were from a wide range of climatic conditions. Also, if the levels of the interacting variables are fixed at different levels, the relationships shown in Figure 13 will be somewhat different.

<u>KCODE</u> The KCODE (crop rotation code for K availability) variable had a linear effect on corn yield modified by interactions with STK1 and DV (Tables 28 and 29). The dYIELD/dKCODE = -0.240 - 0.000410 STK1 + 0.0958 DV. The slope of the negative yield response to KCODE became more negative as STK1 increased and less negative as DV changed from severe to no stress.

At DV = 4, the dYIELD/dKCODE = 0.143 - 0.000410 STK1. At STK1 = 50 and 200, the slopes of the yield response to KCODE were 0.122 and 0.061 q/ha per unit increase of KCODE, respectively. From KCODE = 0 to 60, the yield responses were 7.3 and 3.7 q/ha (11.6 and 5.9 bu/acre), respectively. These responses appear to be more related to N availability than to decreased K availability because of increased crop removal of K as KCODE increased from 0 to 60. If K removal had an effect on corn yield, the effect of KCODE on yield should be more negative at low than at high STK1 levels.

The more negative response to KCODE as coded DV decreased (moisture stress increased) may be due to decreased soil K availability with increasing moisture stress, as had been reported. The positive KCODE*DV interaction, however, may also be more related to N availability than to K availability; both Henao (1976) and Pena-Olvera (1979) had reported significant negative NCODE*DV interactions. Because of the correlation between NCODE and KCODE (r = -0.52), the presence of the KCODE variable may be distorting the effects of NCODE on yield and decreasing the significance of the NCODE*DV interaction which should be of more practical significance than the KCODE*DV interaction in the analysis of state-wide data. In future regression analyses of these data, the KCODE variable should be deleted in an alternative series of models.

<u>NRES1</u> The NRES1 variable (total N applied the previous year) had a positive linear effect on YIELD modified by a negative interaction with PBDCT (Table 28). The dYIELD/dNRES1 = 0.0139 - 0.000529 PBDCT. As PBDCT varied from 0 to 26.3 kg P/ha (54 lb P_2O_5/acre), the slope of the yield response to NRES1 decreased from 0.0139 to 0. At PBDCT levels >26.3 kg P/ha, the NRES1 effect on yield became increasingly negative. The NRES1 effect was discussed previously in the PBDCT subsection.

<u>PH1</u> In MODEL J-10 (Table 28), the PH1 variable (pH of the plow layer) had a linear effect on YIELD modified by DCAL (coded depth to calcareous layer). The dYIELD/dPH1 = 0.437 - 0.00447 DCAL. The slopes of the linear yield response to PH1 were 0.437 and -0.175 for DCAL = 0 (decoded, ≥ 152 cm to calcareous layer) and DCAL = 137 (decoded, 15 cm to calcareous layer), respectively. The slope of the yield response became 0 at DCAL = 98 cm (decoded, 54 cm or 21 in. deep to calcareous layer).

Because PH1 and PHMIN, PH1 and DCAL, and PHMIN and DCAL were intercorrelated (r = 0.65, 0.48, and 0.72, respectively), the pH effect of the subsoil layers between the plow layer and calcareous layer (if present) was partially accounted for by the PH1 and DCAL variables in the model. If the depth to calcareous layer was 152 cm, changes in PH1 had the most effect on YIELD. From PH1 = 0 (pH 5.0) to PH1 = 20 (pH 7.0), ΔYIELD was 8.7 q/ha (14 bu/acre); this was similar to the ΔYIELD computed from the quadratic effect of PH1 on YIELD in MODEL B-30 (Table 17).

As the depth to the calcareous layer became more shallow, PH1 had less effect on yield probably because the less acid subsoil layers above the calcareous layer had higher nutrient availability. As the depth to the calcareous layer decreased from 54 cm to 15 cm (21 to 6 in.), an increasing PH1 had an increasingly negative effect on yield. If the subsurface horizon below the plow layer was calcareous, the observed PH1 had a narrow range of about pH 7.0 to 8.2. The effect of DCAL and the correlated pH levels in the subsoil layers above the calcareous layer should be considered in liming recommendations based on pH of the plow layer.

Although PH1 had a quadratic effect on yield in the final quadratic MODELS A-35 and B-30 (Tables 11 and 17, Figure 5A), it had only a linear effect in MODEL J-10. The linear effect of PH1 and its negative interaction with DCAL, however, describe a positive, zero, and then negative effect of PH1 on yield.

STN The STN (soil test N of the plow layer) variable in MODEL J-10 (Tables 28 and 29) had a curvilinear effect on YIELD modified by positive interactions with NCODE and SLOPE and negative interactions with NBDCT and TWP (S-N location). The effects of STN levels on yield responses to NBDCT and NCODE were discussed previously and shown in Figures 11 and 13. As shown in these figures, increasing STN level had the largest effect on yield at NBDCT = 0 and NCODE = 40 (4th-year corn). With higher NBDCT levels and on 1st-year and 2nd-year corn, the STN level had little effect on yield. From 160 to 320 kg N/ha on 3rd-year and 4th-year corn, however, the yield response to STN level decreased but still was positive.

Soil tests for N were discontinued by the Iowa State Soil Testing Laboratory many years ago because it was less useful as N rates for corn increased. However, it could be used to increase the efficiency of N fertilizer on corn, particularly if N costs continue to increase.

The effects of SLOPE and TWP on the yield response to STN level can be shown by the simplified partial derivative at NBDCT = 160 and NCODE = 30, as follows: dYIELD/dSTN = 0.427 - 0.00418 STN + 0.0148 SLOPE - 0.0060 TWP. At coded TWP = 20 (T85N) and at SLOPE = 0, 10, and 20, the STN levels at YMAX were 73, 109, and 144 pp2m N, respectively. As SLOPE increased (along with decreased THAHOR and organic matter), the STN level required for YMAX increased to beyond the observed range of values. The increase of the STN level associated with YMAX also showed that the yield responses to STN level increased as SLOPE increased.

At SLOPE = 8 and at coded TWP = 5, 20, and 35 (T70N, T85N, and T100N, respectively), the STN levels at YMAX were 123, 102, and 80 pp2m N, respectively. From southern to northern Iowa, the STN levels required for YMAX decreased and ΔYIELD to STN levels also decreased. The effect of TWP on yield response to STN level may be related to the higher yield potential in southern Iowa (Table 17, Figure 6A) because of a longer growing season and later maturing corn grown, increasing organic carbon levels from south to north, and perhaps to partial confounding because level to gently sloping, till-derived soils were prevalent in northern Iowa and sloping, loess-derived soils were prevalent in southern Iowa in these data.

STP1 The STP1 (soil test P of the plow layer) variable had a curvilinear effect on YIELD modified by negative interactions with CRW and MANURE and a positive one with DV. The partial derivative was dYIELD/dSTP1 = 0.228 - 0.00480 STP1 - 0.00467 CRW - 0.00175 MANURE + 0.0359 DV. The level of STP1 associated with YMAX decreased as CRW (rootworm damage) and MANURE increased. As DV increased (from stress to none), however, the STP1 associated with YMAX increased. The effect of the MANURE*STP1 interaction on YIELD was discussed in the MANURE subsection.

The effects of the CRW*STP1 and the STP1*DV interactions on the yield response to STP1 levels are illustrated in Figure 14. The constant values of the interacting variables were: PLDEN = 600, NBDCT = 180, RL3 = 0, CB1 = 2, MANURE = 0. KCODE = 5, DRAIN = 40, PAWC = 280, and STK1 = 200. The yield response to STP1 level decreased with increasing CRW (Figure 14). At CRW = 10, 30, and 50, the YMAX occurred at STP1 levels of 64, 44, and 25 pp2m P, respectively, at moderate moisture stress.

The simplified partial derivative at CRW = 10 and MANURE = 0 is: 0.181 - 0.00480 STP1 + 0.0359 DV. At DV levels of 2, 3.5, and 5, the YMAX occurred at 53, 64, and 75 pp2m P, respectively. The latter two STP1 values were greater than the upper limit plotted in Figure 14. With no moisture stress, yield responses to STP1 levels were greater than with

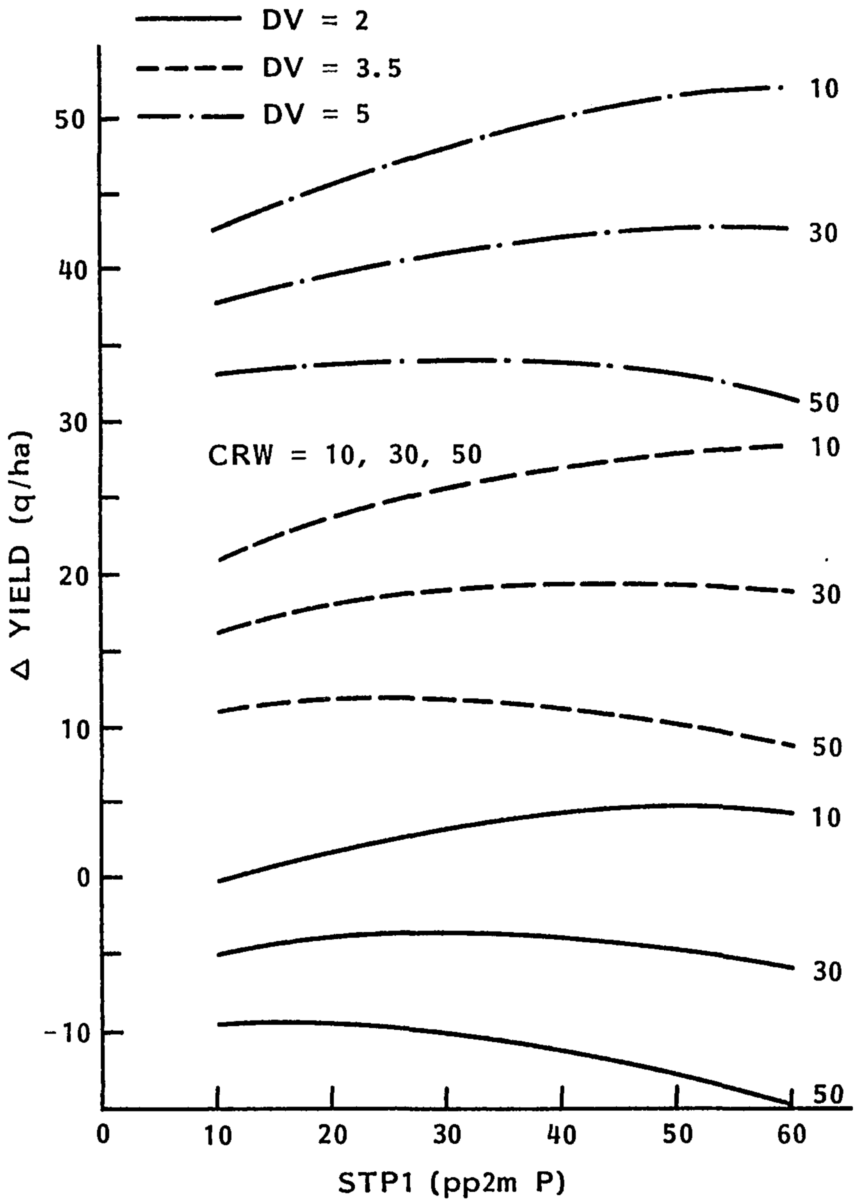


Figure 14. Change in yield (ΔYIELD) with soil test P of the plow layer (STP1) at different corn root damage (CRW) and moisture stress index (DV) levels

moisture stress.

STK1 The STK1 (soil test K of the plow layer) variable in MODEL J-10 (Tables 28 and 29) had a linear effect on YIELD modified by four negative interactions with NBDCT, MANURE, KCODE, and BIO. All of these interactions except that with BIO were discussed previously. The partial derivative was dYIELD/dSTK1 = 0.0602 - 0.0001575 NBDCT - 0.000398 MANURE - 0.000410 KCODE - 0.00643 BIO. An increase of any interacting variable decreased the slope of the linear yield response to STK1 level.

From the simplified derivative with MANURE = 0, KCODE = 20, and BIO = 5, the slopes of the linear yield response to STK1 were 0.020, 0.004, and -0.012 at NBDCT = 0, 100, and 200 kg N/ha. As discussed in the NBDCT subsection, one would expect a more positive effect of STK1 level on yield as NBDCT rates increase because of the higher K requirement.

With NBDCT = 160, MANURE = 0, and KCODE = 20, the simplified partial derivative = 0.027 - 0.00643 BIO. At BIO = 1, 3, and 5 (forest to prairie), the slopes of the linear yield response to STK1 levels were 0.021, 0.008, and -0.005, respectively. An increase of 100 pp2m K in STK1 level thus increased yield 2.1, 0.8, and -0.5 q/ha in the forest, transition, and prairie soils, respectively. Less available subsoil K in forest than in prairie soils may account for these effects.

DV The DV (soil moisture stress index) variable in MODEL J-10 (Tables 28 and 29) was involved in more interactions with other variables on yield than any other one. Its effect on YIELD was modified by positive interactions with PLDEN, NBDCT, CB1, KCODE, and STP1 and negative interactions with RL3, DRAIN, and PAWC. The partial derivative was dYIELD/dDV = 11.24 + 0.0272 PLDEN + 0.0184 NBDCT - 0.0493 RL3 + 0.241 CB1 + 0.0958 KCODE + 0.0359 STP1 - 0.1132 DRAIN - 0.0480 PAWC.

Most of DV interaction effects on yield were discussed previously and rest will be discussed in later subsections. DV had a large effect on yield by itself as shown in Figures 8, 9, 10, and 14. As coded DV increased from 1 to 5 (from severe stress to none), its positive interactions showed that effects of PLDEN, NBDCT, CB1, KCODE, and STP1 on YIELD became greater if initially positive (greater slope) or less if initially negative (smaller negative slope). The negative interactions showed that effects of RL3, DRAIN, and PAWC on YIELD became less if initially positive or became more negative if initially negative.

TWP The coded TWP (township number, S-N location) variable in MODEL J-10 (Tables 28 and 29) had a curvilinear effect on YIELD modified by negative interactions with PLDATE and STN and a positive interaction with PAWC. The partial derivative was dYIELD/dTWP = 0.0938 - 0.01785 TWP - 0.00595 PLDATE - 0.0060 STN + 0.00202 PAWC. The interactions between TWP and PLDATE (Figure 12B) and between TWP and STN have been discussed previously.

For a constant PLDATE = 15 (decoded planting date = May 5) and STN = 50 pp2m, the simplified partial derivative = -0.295 - 0.01785 TWP + 0.00202 PAWC. With PAWC lower than 146 mm H_2O/1.5 m, YIELD decreased at an increasing rate as TWP increased. If PAWC was >146 mm, the TWP associated with YMAX shifted north. The YMAX occurred at coded TWP = 0, 6, and 17 (decoded T65N, T71N, and T82N) for PAWC = 150, 200, and 300 mm, respectively.

RANGE The RANGE (east-west location) variable in MODEL J-10 had a linear effect on YIELD modified by CB2. The partial derivative was dYIELD/dRANGE = -0.122 + 0.00282 CB2. For CB2 = 0, YIELD decreased 0.122 q/ha per unit of RANGE or 5.8 q/ha from RANGE = 0 to 48 (Figure 12A). As CB2 infestation increased, however, the ΔYIELD due to RANGE decreased to 0.

SLOPE From MODEL J-10 (Table 28), the dYIELD/dSLOPE = -0.776 + 0.01475 STN - 0.00379 DCAL. At DCAL = 0 (≥152 cm to calcareous horizon), the slope of the linear yield response to the SLOPE variable varied from -0.334 to 0.404 as STN varied from 30 to 80 pp2m N. The negative effect of SLOPE on yield was expected but not the positive effect above STN = 53.

As coded DCAL increased (decoded depth to calcareous layer decreased), the slope of the linear yield response to the SLOPE variable became more negative. At STN = 50 pp2m, and DCAL = 0 and 137 cm (decoded DCAL of 152 cm and 15 cm), the slopes of the yield response to SLOPE were -0.029 and -0.548, respectively. Thus, the effect of SLOPE on YIELD became more negative as depth to calcareous layer decreased.

THAHOR The THAHOR (thickness of A horizon) variable in MODEL J-10 had a curvilinear effect on YIELD modified by negative interactions with NBDCT and CPL. The dYIELD/dTHAHOR = 0.3113 - 0.00259 THAHOR - 0.000588 NBDCT - 0.00517 CPL.

The negative interactions between THAHOR and CPL and THAHOR and NBDCT are illustrated in Figure 15. Other interacting variables with

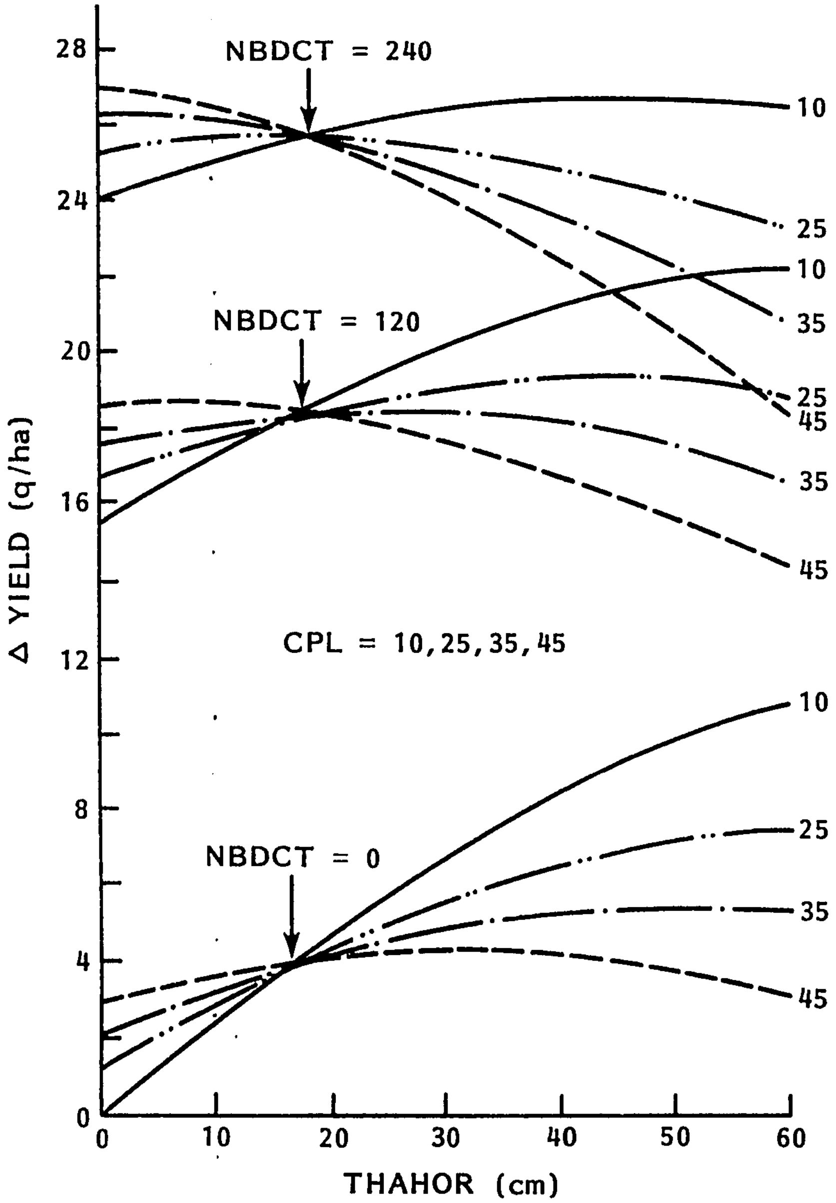


Figure 15. Change in yield (ΔYIELD) with thickness of the A horizon (THAHOR) at different N fertilizer (NBDCT) levels and clay percentages of the plow layer (CPL)

NBDCT and CPL were at: CB2 = 10, NCODE = 30, STN = 50, STK1 = 150, and DV = 4, with units as listed in Table 5. The negative interaction between THAHOR and NBDCT in Figure 15 showed that both the ΔYIELD due to THAHOR and the THAHOR that gave ΔYMAX decreased as NBDCT level increased, as expected. The negative effect of THAHOR on ΔYIELD at the higher CPL levels and, particularly, at the highest level of NBDCT, however, was unexpected. Intercorrelations among THAHOR, SLOPE, CPL, and DRAIN may be causing some distortion of their relationships with YIELD. Some effects of these variables (SLOPE in the previous subsection, THAHOR here, and DRAIN and CLAY in the next subsections) are difficult to explain, but yield predictions from the regression model may be much better because their joint effects on YIELD are accounted for.

The effects of CPL (percent clay of the plow layer) on ΔYIELD from THAHOR levels are shown in Figure 15. Increased CPL, from a loamy sand to a silty clay texture, decreased both the ΔYIELD due to THAHOR greater than 18 cm (7 in.) deep and the THAHOR associated with ΔYMAX. At THAHOR from 0 to 18 cm, there was a reversal of the CPL effect on ΔYIELD due to THAHOR. This effect probably was due to the lower organic matter (OC) level of the sandy than heavier-textured soils. Because no significant NBDCT*CPL interaction occurred, the predicted CPL-THAHOR relationship on ΔYIELD was the same at all NBDCT levels.

<u>DRAIN</u> The DRAIN (drainage class) variable in MODEL J-10 (Table 28) had a curvilinear effect on YIELD modified by interactions with NCODE and DV. The partial derivative of YIELD with respect to DRAIN was dYIELD/dDRAIN = 0.815 - 0.00700 DRAIN - 0.0022 NCODE - 0.1132

DV. The effect of DRAIN on the yield response to NCODE was discussed previously in the NCODE subsection. From the simplified partial derivative with DV = 4, the DRAIN values associated with YMAX were 48.6 (somewhat poor) to 39.1 (moderately well) as NCODE varied from 10 to 40. The ΔYIELD from the DRAIN value at YMAX to DRAIN = 70 (poor) varied from -1.6 to -6.7 q/ha (-2.6 to -10.7 bu/acre) as NCODE increased from 10 to 40 (1st-year to 4th-year corn). Poor drainage thus had a greater adverse effect on yield of continuous corn than of 1st-year corn after meadow.

The interaction between DRAIN and DV is illustrated in Figure 16. Interacting variables were held constant as follows: PLDEN = 600, NBDCT = 180, RL3 = 0, CB1 = 2, NCODE = 30, KCODE = 5, STN = 50, STP1 = 35, and PAWC = 230. From DV = 2 to 5 (severe to no stress), ΔYIELD due to DRAIN level decreased from positive to negative (Figure 16) and DRAIN at ΔYMAX decreased from 75 (poor to very poor) to 26 (excessive to well). With severe moisture stress, the sandy, excessively-drained soils (DRAIN=20) are the first to show stress and yields are reduced markedly. The negative effect of coded DRAIN at DV = 5 (no stress) indicated that excess moisture occurred during the 75-day period from 6 weeks prior to silking to 5 weeks after silking and that this effect is accentuated as drainage becomes poorer. The excess moisture index (EXMO) was designed to characterize only the excess moisture during the early part of the growing season.

CPL The CPL (percentage clay of the plow layer) variable in MODEL J-10 had a linear effect on YIELD modified by a negative

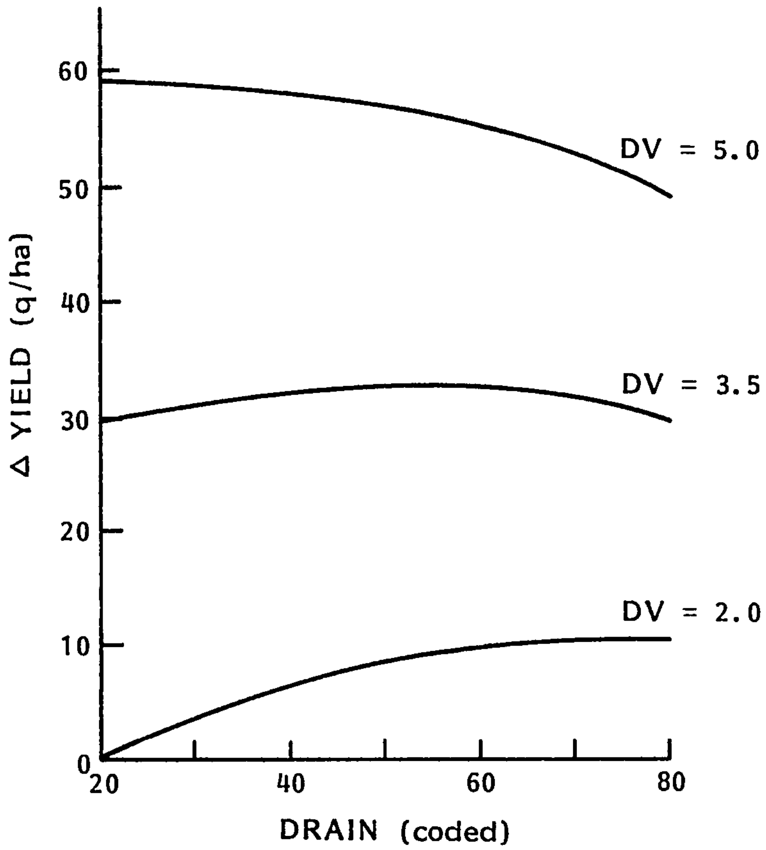


Figure 16. Change in yield (ΔYIELD) with drainage class (DRAIN) at different moisture stress index (DV) levels

interaction with THAHOR. Its partial derivative was dYIELD/dCPL = 0.0859 - 0.00517 THAHOR.

The slopes of the linear yield response on CPL were 0.060, 0.021, and -0.069 q/ha per percent CPL for THAHOR = 5 cm (2 in., severely eroded), 12.5 cm (5 in., moderately eroded), and 30 cm (12 in., not eroded), respectively. Increasing CPL had a decreasing positive effect on YIELD to THAHOR = 17 cm (7 in.) and then it had an increasingly negative effect on YIELD as THAHOR increased above 17 cm thick. These effects are shown in Figure 15. As soil erosion becomes more severe, higher CPL becomes more important, but as THAHOR increases above 17 cm, higher CPL levels had larger negative effects on ΔYIELD. These effects may be related to intercorrelations among several variables discussed in the THAHOR subsection.

<u>BIO</u> The BIO (biosequence) variable in MODEL J-10 had a linear effect on YIELD modified by STK1 and STP2. The partial derivative of YIELD with respect to BIO was dYIELD/dBIO = 0.707 - 0.00643 STK1 + 0.0234 STP2. At STP2 = 30 (not realistic because BIO and STP2 are correlated, r = -0.50), the slopes of the linear yield response to BIO were 0.766 and 0.123 q/ha per unit of coded BIO for STK1 = 100 and 200 pp2m K, respectively. The ΔYIELDS from BIO = 1 (forest) to 5 (prairie) were 3.1 and 0.5 q/ha, respectively.

At STK1 = 120 (low to low-medium), the slopes of the linear YIELD response to BIO were 0.40 and 1.17 q/ha per unit of BIO for STP2 = 20 and 50, respectively. The ΔYIELDS from BIO = 1 to 5 were 1.6 to 4.7 q/ha (2.6 to 7.5 bu/acre).

<u>DCAL</u> The DCAL (depth to calcareous layer) in MODEL J-10 (Tables 28 and 29) had a linear effect on YIELD, modified by three interactions with SLOPE, PH1, and STP2. The dYIELD/dDCAL = 0.0627 - 0.00379 SLOPE - 0.00447 PH1 + 0.00402 STP2. The interacting variables of SLOPE, PH1, and STP2 also had linear effects on YIELD.

The effects of the interactions between DCAL and both SLOPE and STP2 are shown in Figure 17 at two levels of PH1 (pH of the plow layer). Other interacting variables held constant were STN = 50 pp2m and BIO = 5. The ΔYIELD at DCAL = 140 cm (decoded, 12 cm), PH1 = 2.0 (decoded, pH 7.0), SLOPE = 15%, and STP2 = 5 pp2m was set = 0 and all other ΔYIELDS were adjusted to be relative to this 0 value.

At decoded PH1 = 5.5 and STP2 = 5 (very low level), the ΔYIELD was highest if depth to the calcareous horizon was shallow (Figure 17). The ΔYIELD then decreased as the depth to the calcareous horizon increased in the level soils (SLOPE = 0%), but remained constant at site slopes of 15%.

At decoded PH1 = 5.5 and STP2 = 25 pp2m (low-medium level), ΔYIELD decreased as DCAL increased; the decrease was greater at 0% than 15% site slope. Most of the calculated ΔYIELDS for STP2 = 25 pp2m, however, are outside of the range of observed values for STP2. If the 76-107 cm (30-42 in.) layer where STP2 was measured (shown by the vertical dashed lines in Figure 17) became calcareous, the STP2 levels decreased to very low levels (5-8 pp2m P) in all upland and most other soils. In only very few alluvial soils that were calcareous in the subsoil did STP2 levels approach 25 pp2m P. If the plow layer is acid, depth to the

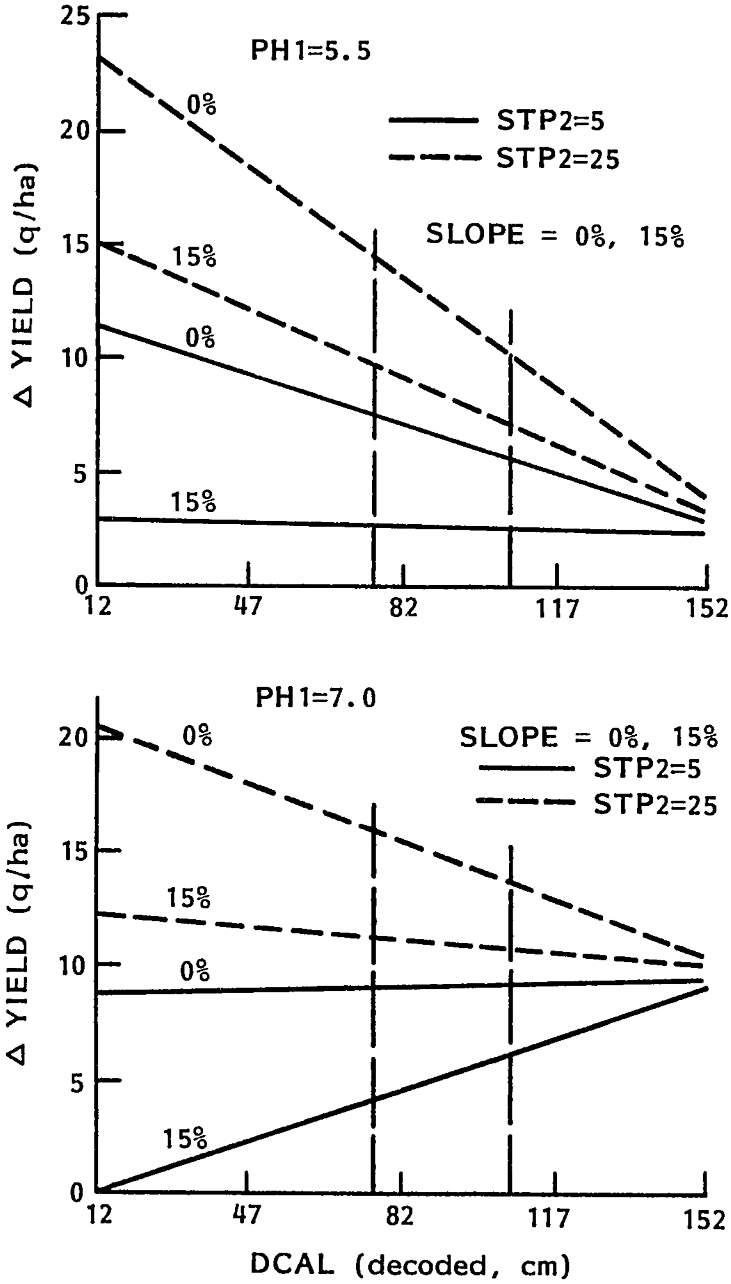


Figure 17. Change in yield (ΔYIELD) with decoded depth to calcareous layer (DCAL) at two levels of soil test P of the subsoil (STP2), site slope (SLOPE), and pH of the plow layer (PH1) (vertical dashed lines show 76-107 cm layer where STP2 was measured)

calcareous layer less than 152 cm (60 in.) had a beneficial effect on YIELD.

The relationships are different between ΔYIELD and DCAL if decoded PH1 = 7.0 because of the PH1*DCAL interaction. At STP2 = 5 pp2m, ΔYIELD increased as DCAL became deeper in the profile with larger differences occurring in the more sloping soils. At the higher STP2 levels, ΔYIELD decreased slightly as DCAL increased below 107 cm (42 in.).

The complex effects of DCAL on corn yield were influenced by several interactions, but the effects in Figure 17 show the general trends.

STP2 The STP2 (soil test P of the 76-107 cm or 30-42 in. layer) had a linear effect on YIELD, modified by two interactions with BIO and DCAL. The partial derivative was dYIELD/dSTP2 = -0.0754 + 0.0234 BIO + 0.00402 DCAL. Its interaction effects with BIO and DCAL have been discussed previously.

At DCAL = 0 (decoded, depth to calcareous layer of 152 cm or 60 in.) the slopes of the yield response on STP2 were -0.052 q/ha per pp2m P increase in the forested soil and 0.042 q/ha per pp2m P increase in the prairie soil. The negative effect of STP2 level on YIELD in the forest soils may be related to a decreased pH in the same layer (and rest of the subsoil) as STP2 increased (r = -0.56). The positive effect of a calcareous layer in the lower subsoil on YIELD was related to less acidity in the subsoil (DCAL subsection). Effects of higher levels of STP2 in the forest soil were offset by adverse effects of lower pH levels. In the prairie soils, higher STP2 levels were more important on

YIELD because the soil test P levels in the upper subsoil were much less than in the forest soils (Salih, 1980).

The STP2*DCAL interaction is only relevant in soils with depth to calcareous layer >107 cm (42 in.) because STP2 decreases to very low levels as DCAL becomes more shallow than 107 cm. This interaction is also involved primarily with the prairie soils because very few of the forested soils had carbonates in the profile.

PAWC The PAWC (plant available water capacity) variable in MODEL J-10 had a curvilinear effect on YIELD, modified by three interactions with RL3, DV, and TWP. The dYIELD/dPAWC = -0.0656 + 0.001017 PAWC - 0.000672 RL3 - 0.0480 DV + 0.00202 TWP. The effects of the PAWC interactions have been discussed in previous subsections.

The interactions of PAWC with DV and TWP are shown in Figure 18. The other interacting variables with PAWC, DV, and TWP were set at: PLDEN = 500, NBDCT = 180, RL3 = 0, CB1 = 2, PLDATE = 15, KCODE = 5, STN = 50, and DRAIN = 40 (in units as listed in Tables 5 and 12). The PAWC associated with YMIN increased as DV increased (Figure 18). For decoded TWP = 85N, the PAWC values associated with YMIN were 119, 190, and 261 mm H_2O/1.5 m for DV = 2.0, 3.5, and 5.0, respectively. The ΔYIELDS to increasing PAWC were mostly positive with severe moisture stress but mostly negative with no moisture stress (Figure 18). High PAWC level would have an advantage for severe moisture stress conditions because it is an important factor in the reserve soil moisture supply. The negative effect of PAWC with no moisture stress is similar to the effect of DRAIN at the same condition (Figure 16). These effects

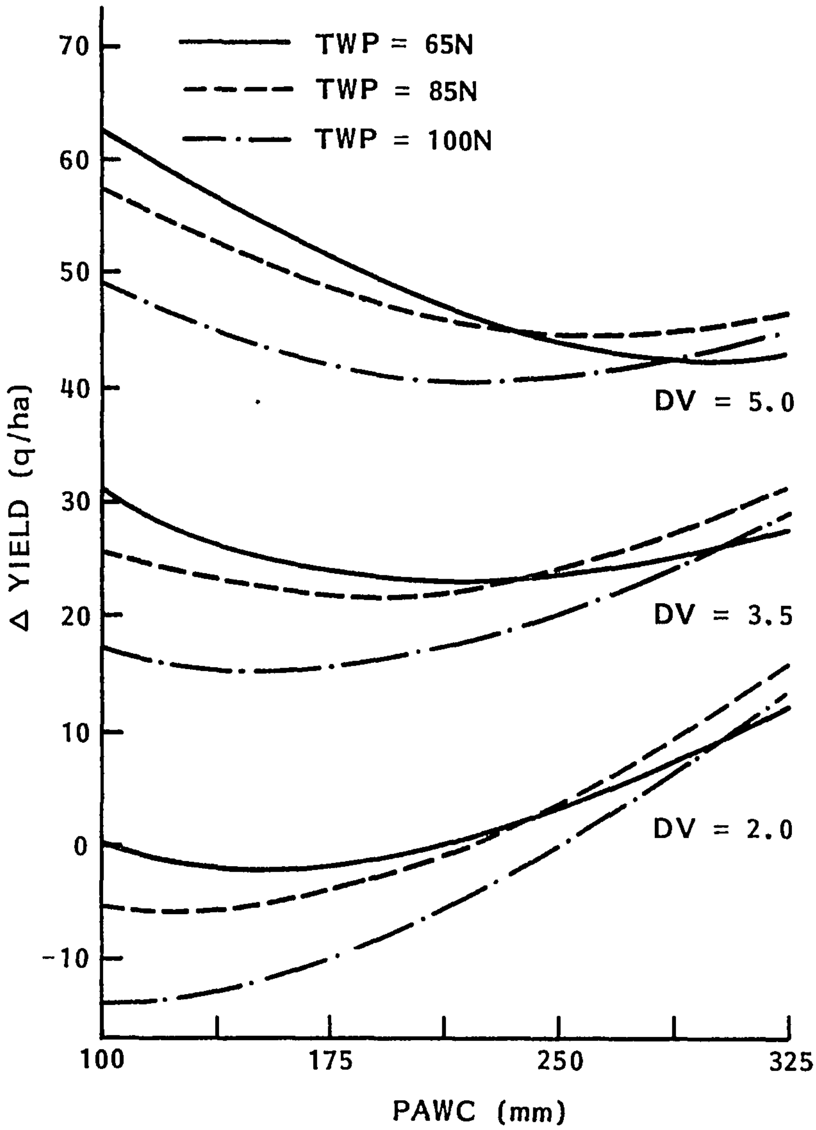


Figure 18. Change in yield (ΔYIELD) with plant available water capacity (PAWC) levels at different moisture stress index (DV) and S-N locations (TWP)

indicate that excess moisture in the summer may have an adverse effect on yield.

For each DV level, the level of PAWC associated with YMIN increased as TWP increased (Figure 18). The increasing PAWC had less positive effect on ΔYIELD in southern Iowa (TWP = 65N) than in northern Iowa with severe moisture stress. With no stress, PAWC level had a greater negative effect in southern Iowa than in northern Iowa.

Summary of final yield prediction model

Interaction variates significant at the 2-10% level prior to their deletion in the MODELS C to G series were retested in the selection of the final yield prediction model in the MODEL J series. The 22 interactions retested were combined with all variates retained in MODEL H-11 plus two other variates; the initial MODEL J-1 had 34 linear, 15 squared, and 48 interaction variates and an R^2 = 0.682. Stepwise, backward elimination of nonsignificant variates gave the final yield prediction regression model, MODEL J-10. This model had 80 variates, including 33 linear, 14 squared, and 33 interaction variates; 51 variates were significant at the 1% level, 20 were significant at the 5% level, 4 were significant at the 10% level, and 5 nonsignificant linear variates were retained because each was involved in one or more significant interactions. The R^2 of 0.681 for final MODEL J-10 was slightly higher than the R^2 of 0.677 for MODEL H-11, only a slight gain from retesting the 22 interactions and retaining a few of them.

The DV variable had 8 interactions, 6 of them with management variables; NBDCT had 6 interactions; STN and STK1 had 4 interactions; CB2, NCODE, STP1, TWP, DCAL, and PAWC had 3 interactions; PLDEN, RL3, MANURE, KCODE, SLOPE, THAHOR, DRAIN, BIO, and STP2 had 2 interactions; and CRW, CB1, PLDATE, PBDCT, NRES1, PH1, RANGE, and CPL had only 1 interaction.

Six variables (WEEDS, TILE, SL1, PROW, EXMO, and PALEO) had only a linear effect and no interaction effect on yield. Fourteen variables (PLDEN, NBDCT, RL3, CB1, CB2, PLDATE, PBDCT, NCODE, STN, STP1, TWP, THAHOR, DRAIN, and PAWC) had a quadratic effect on yield modified by one or more interactions. The other 13 variables had a linear effect on yield modified by one or more interactions.

The effects of the variables on yield were examined from (1) the partial derivatives of yield with respect to the variable, and/or (2) by computing the ΔYIELD values for selected combinations of levels of 2 or 3 variables after setting the levels of the interacting variables equal to selected constants and those of all others equal to zero. Most of the variable effects on yield were complex because of interactions.

Both the PLDEN and NBDCT effects on yield were influenced by strong interactions with DV (moisture stress). The yield responses of both increased and the levels of PLDEN and NBDCT associated with YMAX increased as moisture stress decreased.

The yield responses to NBDCT also were markedly affected by interrelated interactions with NCODE and STN. The responses to NBDCT increased from 1st-year to 4th-year corn and decreased as STN level increased. Maximum responses occurred on 4th-year corn on soils with very low STN levels. The NCODE effect on yield also became more negative as drainage became poorer. As THAHOR decreased to 0 cm (severe erosion), the NBDCT effect on yield increased. As SLOPE increased, the yield response to STN level increased. All of the management and soil variables related to availability of N for corn (NBDCT, NCODE, STN, DRAIN, SLOPE, and THAHOR) thus had interrelated effects on yield.

The planting date associated with YMAX varied from May 10 in extreme southern Iowa to April 26 in extreme northern Iowa. Delayed planting had about twice the negative effect on yield in northern than in southern Iowa.

Yield losses from corn insects were influenced by several interactions. These included negative CRW*STP1, RL3*DV, RL3*PAWC, CB2*PLDEN, and CB2*NBDCT ones and positive CB1*DV and CB2*RANGE interactions. Of particular importance, higher CB2 (second-brood corn borer) levels had an increasingly detrimental effect on corn yield as PLDEN and NBDCT levels increased (higher potential yields). All corn was harvested from the plots; harvest losses due to root lodging, stalk breakage, and dropped ears, therefore, were not included in the estimated yield losses from insect and disease infestations.

The DV (moisture stress index) variable had the largest effect on yield and was involved in the most interactions. As stress decreased from severe to none, its positive interactions showed that the effects of PLDEN, NBDCT, CB1, KCODE, and STP1 on yield became more positive or less negative. Its negative interactions showed that the effects of RL3, DRAIN, and PAWC on yield became less positive or more negative as moisture stress decreased.

Increased PH1 (pH of plow layer) had the most positive effect on yield at DCAL (depth to calcareous layer) ≥152 cm (60 in.). As DCAL decreased to 54 cm (21 in.) and then became more shallow, the effect of increasing PH1 on yield decreased to 0 and then became negative. The DCAL, PH1, SLOPE, and STP2 (subsoil P) variables also had interrelated effects on yield. As DCAL became more shallow, the interaction effects with the other variables had more marked effects on yield. These relationships indicate that subsoil pH affects corn yield; the effects of DCAL and the subsoil pH level should be considered in liming recommendations based on pH of the plow layer.

The interaction between DRAIN and DV showed that YMAX occurred on the poorly-drained soils if severe stress occurred but on well-drained soils if no stress occurred. The negative effect on yield of poorer drainage if no moisture stress occurred indicated that excess moisture occurred during the period of 6 weeks before to 5 weeks after silking over which the DV index was computed.

The BIO (biosequence) variable had interactions with STK1 and STP2. Yields of prairie soils were greater than those of the forest soils at low STK1 levels but not at high STK1 levels. Yield response to increased STP2 level was negative in the forest soils but positive in the prairie soils. The biosequence comparisons may be related to less subsoil K in the forest soils and lower subsoil pH levels associated with higher STP2 levels (r = -0.56), particularly in the forest soils.

All other interaction effects between variables on corn yield were discussed; several were also illustrated with yield response curves.

SUMMARY AND CONCLUSIONS

Corn yield production is influenced by many variables within the broad categories of management, climatic, soil, and location groups of variables. Many researchers have studied the effects of two or three variables on yield and their relationships. Their results frequently are difficult to apply to different locations and years having different soil and environmental conditions. Efforts have been made to relate simultaneously all variables known to influence yield through the use of multiple regression.

Management, climatic, soil, and location data related to corn yields in Iowa were collected from 1957 to 1970 in 15 counties representing most major soil association areas. From these data, Morris (1972) derived the climatic indexes and tested them in corn yield regressions together with several management variables. Henao (1976) then modified the climatic indexes and selected the important soil variables in the presence of selected management and climatic variables in his yield regressions. Pena-Olvera (1979) studied the intercorrelated variables, modified and tested the climatic indexes, and selected the most significant soil, management and climatic indexes in his yield regressions, using data from seven western Iowa counties. The remaining group of variables that needed to be studied in detail were the management variables along with the recomputed climatic indexes of Pena-Olvera (1979), using data from all 15 counties.

The objectives of this research were: (1) to test and select the most significant management variables in the presence of the modified climatic variables; (2) to combine these with soil and location variables to test and select the most significant variables in a series of quadratic regression yield models; (3) to test and select the most significant interactions between variables in a series of models; and (4) to select a final multiple regression quadratic model with linear by linear interactions for predicting Iowa corn yields. The relationships between corn yield and groups of two or three interaction variables in the final prediction model were then interpreted and illustrated.

Four steps or stages were used to select the final yield prediction model. First, the most important management variables in the presence of climatic variables were selected in a series of quadratic models, the MODEL A series. Second, soil variables were added to the selected variates from the final model of the MODEL A series and the most important soil variables were selected in a series of quadratic models, the MODEL B series. Third, many of the interactions between the selected variables from the final MODEL B series were added and tested in a series of models (MODELS C to H series) to select the most significant interaction variates to include in the final model. Fourth, the most significant linear, quadratic, and interaction variates were selected for the final prediction model of corn yield on management, climatic and soil variables in the MODEL J series.

The criteria for retention of given variates in the model were: (1) after the t-test for significance was applied to each of the partial regression coefficients, only those were retained in the equation whose probability was less than $\alpha = 0.15$ initially and less than $\alpha = 0.10$ in final stages of model selection, except that the linear variate was retained regardless of its significance if its squared or any interaction variate was significant at $\alpha = 0.10$; (2) no variables were to be included with correlations $>\pm 0.60$; and (3) after comparing correlated variables in alternate models, the one of the pair that gave the higher R^2-value, although only slightly higher in some cases, was retained in subsequent models and the other was deleted. The fitting of the multiple regression equations was done by using the computer program, the Helarctos II (Kennedy, 1971).

Selection of Management Variables

The management variables included in this study were grouped as environmental, tillage and planting, fertility management, and soil tests of the plow layer. Two modified climatic variables, the soil moisture stress index (DV) and excess moisture index (EXMO), were included in all regressions. The data included in this study were collected from 2657 observations (site/years) in 15 counties from 1957 to 1970.

Simple correlation coefficients among 73 original management variables were initially examined. The variables deleted from further analysis because of high correlations or because they could be combined into one variable included time trend, ear weight, moderate and severe root lodging, second-brood corn borer in the stalks and ear shanks, grassy and broadleaf weeds, hill spacing of hill-dropped corn, several highly-correlated residual fertilizer variables, and several tillage variables.

In the initial quadratic regression model, the MODEL A series, 49 management variables, 2 climatic variables, and a time period (TIME) variable were tested to select the most important management variables for predicting Iowa corn yields. Among the management variables were: (1) 8 environmental variables of percent barren plants (BARR), percent total root lodged plants (RL3), corn root damage (rootworm) rating (CRW), percent stalk-lodged plants broken below the ear node (SL1), first-brood corn borer infestation (CB1), second-brood corn borer infestation (CB2), total weeds (WEEDS), and insecticide effectiveness rating (INSEFF); (2) 13 tillage and planting variables of time of plowing (PLOW), number of tillage operations after plowing (TILLAFT), planting date (PLDATE), planting method (PLMETH), plant density (PLDEN), row width (ROWWID), row direction (ROWDIR), number of times rotary hoed and cultivated (CULT), 75% silking date (SLKDATE), percent slope of the site area (SLOPE), percent slope of corn rows through the harvest area (ROWSLOPE), ratio of ROWSLOPE/SLOPE (SLRATIO), and distance to tile line (TILE); (3) 23 fertility management variables of lime application (LIME), manure application (MANURE), row fertilizer application (ROWFERT), total N, P, and K applied in row fertilizer (NROW, PROW, and KROW), total N, P, and K fertilizer other than row-applied nutrients (NBDCT, PBDCT, and KBDCT) total N, P, and K from manure and fertilizer (NTOTAL, PTOTAL, and KTOTAL), total N, P, and K fertilizer (NFERT, PFERT, and KFERT), crop sequence code for N and K availability (NCODE and KCODE), total N, P, and K (manure + fertilizer) applied previous year (NRES1, PRES1, and KRES1), total P and K (manure + fertilizer) applied 2 years previously (PRES2 and KRES2), and total P (manure + fertilizer) applied 3 years previously (PRES3); and (4) 5 soil tests of plow layer variables of soil pH (PH1), buffer pH (PHB), soil test N (STN), soil test P (STP1), and soil test K (STK1). The symbols for the variables will be used henceforth.

Correlations between variables were first examined to determine the model selection steps needed to retain variables which were not correlated greater than r = ±0.60. Correlations between fertility management variables were particularly high. A series of alternate models were tested to determine which variables could be retained to minimize correlation between variables and yet maximize the R^2 of the prediction equation.

The initial MODEL A-1 had an R^2 of 0.77. Deletion of the BARR and SLKDATE variables reduced the R^2 to 0.61. They were deleted from any further analysis because both were yield components and SLKDATE was highly correlated with PLDATE. In alternate MODELS A-4 to A-27, the most important variables from different groups of correlated variables were selected for further analysis. Stepwise, backward elimination of nonsignificant variates was then performed in MODELS A-28 to A-35. A linear variate was retained, however, regardless of its significance if its squared term was significant.

MODEL A-35 with an R^2 of 0.603 was selected as the final model; it had 42 variates, 27 linear and 15 squared terms. All regression coefficients of the squared variates in the quadratic functions and most of the linear variates in the linear functions were significant at the 1 or 5% level. No variables were correlated greater than r = ±0.58 in the final model.

The importance of selected groups of variables was evaluated by deleting them alternately from final MODEL A-35. Their relative importance for explaining yield variation was: 2 climatic variables (mostly DV) > 5 tillage and planting variables (mostly PLDEN) > 4 soil test variables > 6 environmental variables > 5 fertility management variables (mostly NBDCT) > 2 crop rotation variables (mostly NCODE).

The variates in final MODEL A-35 which were retained for testing in the next model series with the soil variables were: (1) linear functions of CRW, SL1, WEEDS, TILLAFT, PLMETH, CULT, ROWSLOPE, TILE, NRES1, KCODE, STK1, and EXMO; and (2) quadratic functions (linear and squared variates) of RL3, CB1, CB2, PLDATE, PLDEN, SLOPE, MANURE, PROW, NBDCT, PBDCT, NCODE, PH1, STN, STP1, and DV.

The effect of each variable on yield was discussed or discussed and illustrated using the regression statistics of final MODEL A-35. Most of the effects of the variables on yield were as expected.

Selection of Soil Variables

Soil variables which had the most important effects on yield, based on the previous research by Henao (1976) and Pena-Olvera (1979), were next selected in the presence of the 42 management and climatic variates selected in the MODEL A series. Data for the 25 soil and location variables were collected from 678 sites where yield data had been obtained.

The soil and location variables were: plant available water capacity (PAWC), township number or S-N location (TWP), range number or E-W location (RANGE), erosion class (EROS), thickness of A horizon (THAHOR), organic carbon in 0-51 cm (0-20 in.) layer (OC), natural internal drainage class (DRAIN), clay in the plow layer (CPL), maximum clay in subsoil (CMAX), depth to midpoint of horizon with CMAX (DCMAX), subsoil group rating (SUBGRP), biosequence (BIO), bulk density of 76-102 cm (30-42 in.) layer (BD), loess 51-127 cm (20-50 in.) thick over till or paleosol (LOESS/T), till parent material (TILL), paleosol parent material (PALEO), sand parent material (SAND), colluvium parent material in loess areas (COLLUV), alluvium parent material (ALLUV), minimum pH in subsoil (PHMIN), depth to midpoint of PHMIN horizon (DPHMIN), depth to top of carbonate layer (DCAL), pH of 76-107 cm (30-42 in.) layer (PH2), soil test P of 76-107 cm (30-42 in.) layer (STP2), and soil test K of 30-61 cm (12-24 in.) layer (STK2). The symbols of these variables will be used henceforth.

The initial quadratic model of the MODEL B series included linear variates of all soil and location variables and 19 squared variates of all except the 6 parent material variables which were dummy variables coded 0 or 1. The correlations between variables were first examined. Many soil variables were involved in one or more correlations greater than ± 0.60. Alternate regression models were used to select the most important variables of the highly correlated pairs or groups of variables for retention in the yield regressions. The restrictions was again applied that no variables correlated greater than ± 0.60 were to be included in the final regression model.

The complete model with 86 variates, MODEL B-1, had an R^2 of 0.638.

The highly correlated pH-related texture-related, and organic matter-related soil variables were tested in alternate MODELS B-2 to B-24. After these variable selection steps, no soil variables were correlated greater than r = ±0.53. The nonsignificant variates were then deleted stepwise in MODELS B-25 to B-30. MODEL B-30 with 58 variates was the final model; addition of the selected soil variates increased the R^2 from 0.603 in MODEL A-35 to 0.633 in MODEL B-30. Three management variates (CULT, TILLAFT, and $PROW^2$) were deleted because of nonsignificance.

The final quadratic MODEL B-30 of yield on management, climatic, and soil variables had 37 linear and 21 squared variates ($R^2 = 0.633$). All squared variates were significant at the 1% or 5% level, except PBDCT and PAWC which were significant at the 15% level. Variables with only linear variates in final MODEL B-30 which were not significant at the 5% level were PLMETH (10% level), ROWSLOPE and DPHMIN (15% level), and TILL and STP2 (not significant at the 15% level). The TILL and STP2 variates were retained to test their interactions in the next series of models.

The variables retained in final MODEL B-30 for inclusion in the next series of interaction models included: (1) linear functions (linear variates only) of PLMETH, WEEDS, CRW, SL1, ROWSLOPE, TILE, PROW, NRES1, KCODE, STK1, EXMO, BIO, TILL, PALEO, DPHMIN, and STP2; and (2) quadratic functions (linear and squared variates) of PLDEN, PLDATE, RL3, CB1, CB2, MANURE, NBDCT, PBDCT, NCODE, PH1, STN, STP1, DV, PAWC, TWP, RANGE, SLOPE, THAHOR, DRAIN, CPL, and DCAL.

Most of the management and climatic variables had similar effects on yield as they had in MODEL A-35. The levels of NBDCT, PBDCT, and PH1 associated with maximum yield, however, were somewhat different in this model than in MODEL A-35. All of the soil variables had similar effects on yield as had been reported by Henao (1976) except PAWC: minimum yield was associated with a medium level of PAWC instead of a low level, as expected. The effects of the soil variables on yield were interpreted and most of the curvilinear effects were illustrated.

Selection of Interaction Variates

Interactions between the management, climatic, and soil variables retained in final MODEL B-30 were selected in the MODELS C to H series of regressions. Not all 703 interactions between the 37 variables in MODEL B-30 and the ALLUV variable could be tested because of limited funds. From the previous research of Henao (1976) and Pena-Olvera (1979) and *a priori* agronomic information, 195 logical interactions were selected to be tested in the MODELS C to G series of regressions. The 60 variates of MODEL B-30 were used as the base set of variates. The 195 interactions were randomly assigned, 39 to each initial model of the MODELS C to G series.

The most significant interactions in each model were selected by stepwise, backward elimination of the least significant variates. Interaction variates significant at the 0.01 to 0.02 level were retained in each final model. This rigid selection was followed to reduce the total number of interactions in final MODELS C to G to 42, which was the number that could be included in the MODEL H series. The 21 interaction variates that were significant at the 0.02 to 0.10 level prior to deletion were selected to be retested in a later model series.

The 42 most significant interactions from final MODELS C to G were then combined and tested in the MODEL H series with the base set of variates from MODEL B-30, except for five linear and squared variates deleted because of nonsignificance in the MODELS C to G series. After a series of stepwise, backward eliminations of nonsignificant variates, MODEL H-11 was selected as the final model. It had 74 variates including 33 linear, 15 squared, and 26 interaction terms. Addition of the interaction variates increased the R^2 of MODEL H-11 to 0.677 from the R^2 of 0.633 for quadratic MODEL B-30.

Selection of Final Yield Prediction Model

Interaction variates significant at the 2-10% level prior to their deletion in the MODELS C to G series were retested in the selection of the final yield prediction model in the MODEL J series. The 22 interactions retested were combined with all variates retained in MODEL H-11 plus two other variates; the initial MODEL J-1 had 34 linear, 15 squared, and 48 interaction variates and an R^2 = 0.682. Stepwise, backward elimination of nonsignificant variates gave the final yield prediction regression model, MODEL J-10. This model had 80 variates, including 33 linear, 14 squared, and 33 interaction variates; 51 variates were significant at the 1% level, 20 were significant at the 5% level, 4 were significant at the 10% level, and 5 nonsignificant linear variates were retained because each was involved in one or more significant interactions. The R^2 of 0.681 for final MODEL J-10 was slightly higher than the R^2 of 0.677 for MODEL H-11, only a slight gain from retesting the 22 interactions and retaining a few of them.

The DV variable had 8 interactions, 6 of them with management variables: NBDCT had 6; STN and STK1 had 4; CB2, NCODE, STP1, TWP, DCAL, and PAWC had 3; PLDEN, RL3, MANURE, KCODE, SLOPE, THAHOR, DRAIN, BIO, and STP2 had 2; and CRW, CB1, PLDATE, PBDCT, NRES1, PH1, RANGE, and CPL had only 1 interaction.

Six variables (WEEDS, TILE, SL1, PROW, EXMO, and PALEO) had only a linear effect and no interaction effect on yield. Fourteen variables (PLDEN, NBDCT, RL3, CB1, CB2, PLDATE, PBDCT, NCODE, STN, STP1, TWP, THAHOR, DRAIN, and PAWC) had a quadratic effect on yield modified by one or more interactions. The other 13 variables had a linear effect on yield modified by one or more interactions.

The effects of the variables on yield were examined from (1) the partial derivatives of yield with respect to the variable; and/or (2) by computing the ΔYIELD values for selected combinations of levels of 2 or 3 variables after setting the levels of the interacting variables equal to selected constants and those of all others equal to zero. Most of the variable effects on yield were complex because of interactions; the most important ones are summarized.

Both the PLDEN and NBDCT effects on yield were influenced by strong interactions with DV (moisture stress). The yield responses of both increased and the levels of PLDEN and NBDCT associated with YMAX increased as moisture stress decreased.

The yield responses to NBDCT also were markedly affected by interrelated interactions with NCODE and STN. The responses to NBDCT increased from 1st-year to 4th-year corn and decreased as STN level increased. Maximum responses occurred on 4th-year corn on soils with very low STN levels. The NCODE effect on yield also became more negative as drainage became poorer. As THAHOR decreased to 0 cm (severe erosion), the NBDCT effect on yield increased; the THAHOR effect on yield also was modified by soil texture. As the soil slope increased, the yield response to STN level increased. All of the management and soil variables related to availability of N for corn (NBDCT, NCODE, STN, DRAIN, SLOPE, and THAHOR) thus had interrelated effects on yield.

The planting date associated with YMAX varied from May 10 in extreme southern Iowa to April 26 in extreme northern Iowa. Delayed planting had about twice the negative effect on yield in northern than in southern Iowa.

Yield losses from corn insects were influenced by several interactions. The negative effect of CRW (root damage rating from corn rootworm) increased with a higher STP1 level. The negative effect of root lodging (part of which was due to rootworm damage) increased as moisture stress decreased. The CB1 (first-brood corn borer) effect on yield became more negative as moisture stress increased. Higher CB2 (second-brood corn borer) levels had an increasingly detrimental effect on corn yield as PLDEN and NBDCT levels increased (higher potential yields). Increased CB2 level also decreased yield more in eastern than western Iowa. Stalk lodging due to corn borer and disease damage had only a linear negative effect on yield. All corn was harvested from the plots;

the harvest losses due to root lodging, stalk breakage, and dropped ears, therefore, were not included in the estimated yield losses from insect and disease infestations.

The DV (moisture stress index) variable had the largest effect on yield and was involved in the most interactions. As stress decreased from severe to none, its positive interactions showed that the effects of PLDEN, NBDCT, CB1, KCODE, and STP1 on yield became more positive or less negative. Its negative interactions showed that the effects of RL3, DRAIN, and PAWC on yield became less positive or more negative as moisture stress decreased.

Increased PH1 (pH of plow layer) had the most positive effect on yield at DCAL (depth to calcareous layer) ≥152 cm (60 in.). As DCAL decreased to 54 cm (21 in.) and then became more shallow, the effect of increasing PH1 on yield decreased to 0 and then became negative. The DCAL, PH1, SLOPE, and STP2 (subsoil P) variables also had interrelated effects on yield. As DCAL became more shallow, the interaction effects with the other variables had more marked effects on yield. These relationships indicated that subsoil pH affected corn yield; the effects of DCAL and the subsoil pH level should be considered in liming recommendations based on pH of the plow layer.

The interaction between DRAIN and DV showed that YMAX occurred on the poorly-drained soils if severe stress occurred but on well-drained soils if no stress occurred. The negative effect on yield of poorer drainage if no moisture stress occurred indicated that excess moisture occurred during the period of 6 weeks before to 5 weeks after silking over which the DV index was computed.

The BIO (biosequence) variable had interactions with STK1 and STP2. Increasing STK1 levels had more effect on yield of the forest than of the prairie soils; yields of prairie soils were greater than those of the forest soils at low STK1 levels but not at high STK1 levels. Yield differences between prairie and forest soils were larger if both had high STP2 (subsoil P) levels. Yield response to increased STP2 level was negative in the forest soils but positive in the prairie soils. The biosequence comparisons may be related to less subsoil K in the forest soils and lower subsoil pH levels associated with higher STP2 levels (r = -0.56), particularly in the forest soils.

All other interaction effects between variables on corn yield were discussed. Several of them were illustrated with yield response curves.

Conclusions and Recommendations

The final yield prediction MODEL J-10 had 80 variates of 33 management, climatic, and soil variables and an $R^2 = 0.681$. The effects of most of the variables in the model and their interactions on yield were as expected and could be explained. The final MODEL J-10, therefore, can be used for predicting the corn yields of the different soil mapping units in Iowa.

The soil variables included in this final prediction model and their interactions with various management variables should be considered in the corn management recommendations. The subsoil pH level and depth to calcareous layer, for example, need to be considered in liming recommendations based on pH of the plow layer.

The use of the KCODE variable caused some difficulties in interpretation of crop sequence affects on yield in the final model. Because of the high correlation between NCODE and KCODE (r = -0.52), the KCODE variable may have distorted the effect of NCODE on yield. For additional regressions, the KCODE variable ought to be deleted. The NCODE variable also should be recoded to separate the effects of corn following corn from corn following soybeans.

Due to increased use of fertilizer along with higher plant density levels after about 1963, improvement of the prediction model may be obtained by dividing and analyzing separately the data from two time periods, 1957-1963 and 1964-1970. The data from the eastern and western parts of the state also should be analyzed separately. The model selection steps will be detailed because the relative importance of several variables may differ between the two time periods and areas of the state.

Some of the predicted variable effects deviated from the expected at the extreme ranges of the variables. These effects may be minimized by using curvilinear functions other than the quadratic one and by using higher-order interactions along with the linear*linear ones used in this study.

Several special studies can be conducted utilizing part of the observations. These include methods of P and K application, times of N application, depths to parent material characteristics, and effects of fertilizer variables in the absence of manured sites. When the data were transformed and transferred to new data decks for this study, the variables for these special studies were included.

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APPENDIX A

Table A1. Data listing for field and management variables on original computer card 1

Column	Identification or variable
1-4	Job account number
5	Card no. = 1
6-7	County code: Adams = 02; Bremer = 09; Cass = 15; Clay = 21; Crawford = 24; Fayette = 33; Hamilton = 40; Harrison = 43; Howard = 45; Keokuk = 54; Linn = 57; Lyon = 60; Muscatine = 70; Wayne = 93; Woodbury = 97
8-9	Year: last 2 digits for 1957 to 1970
10-11	Site number (relocated sites numbered from last-numbered initial site in the county)
12-14	Corn yield to nearest whole bushel per acre (adjusted for estimated yield loss due to hail and disease damage and harvest before physiological maturity)
15-16	Time trend: 1957 = 1 to 1970 = 14
17-18	Frost damage in the fall, listed as estimated percent yield loss due to frost or killing freeze before maturity
19-20	Disease damage, listed as estimated percent yield loss due to leaf disease (and to stalk rots if they were known to have caused premature dying of the stalks)
21-22	Date site harvested: coded Aug. 1 = 1 and calculated as follows: in Aug. = Aug. date in Sep. = Sep. date + 31 in Oct. = Oct. date + 61 in Nov. = Nov. date + 92
23-24	Percent grain moisture at the harvest date to the nearest whole percent
25-27	Stand level (stalks per acre) at harvest, listed as stalks per 0.01 acre
28-29	Percent of stalks which were barren

Table A1. (Continued)

Column	Identification or variable
30-31	Average ear weight (pound per stalk), listed as average ear weight x 100
32-33	Percent of stalks moderately root lodged at harvest--leaning between 30° and 60° from vertical (100% = 99)
34-35	Percent of stalks severely root lodged at harvest--leaning more than 60° from vertical (100% = 99)
36-37	Total percent of stalks moderately and severely root lodged at harvest (100% = 99)
38-39	Corn root damage rating due to corn rootworms and based on Peters' rating scale of 1.0 (none) to 6.0 (most severely damaged) and listed as sum of ratings of 10 stalks From 1964 to 1970, root damage ratings were made from a sample of 10 root systems per site. From 1957 to 1963, damage ratings for the sites were estimated from 1964-1970 averages, from Turpin's regression equation calculated from 1964-1970 data, and from adjustments based on area of the state and crop sequence
40	Insecticide effectiveness based on the Turpin-Peters rating scale of 1 = no insecticide used to 9 = most effective insecticides and modified by Dumenil in May, 1972
41-42	Corn leaf aphid infestation rating based on Peters' rating scale of 1.0 = none to 5.0 = most severe infestation and listed as rating x 10; ratings were made only in 1967 to 1970; no data for earlier years listed as 00
43-44	Percent of stalks broken over below the ear node at harvest (100% = 99)
45-46	Percent of stalks broken over at or above the ear node at harvest (100% = 99)
47-48	First-brood corn borer infestation, listed as number of cavities (feeding areas) per 10 stalks
49-50	Second-brood corn borer infestation in the ear shanks, listed as number of cavities per 10 stalks (100 or more = 99)
51-52	Second-brood corn borer infestation in the stalks, listed as number of cavities per 10 stalks (100 or more = 99)

Table A1. (Continued)

Column	Identification or variable
53-54	Total second-brood corn borer infestation in the ear shanks and stalks, listed as total number of cavities in the shanks and stalks per 10 stalks (100 or more = 99; only 5 observations in all years had more than 99 second-brood cavities per 10 stalks)
55-56	Percent of stalks showing leaf feeding due to first-brood corn borer (0% observed listed as 01, 100% observed listed as 99, and no data in earlier years listed as 00)
57-59	Grassy weeds, listed as lb/0.1 acre (air-dry)
60-62	Broadleaf weeds, listed as lb/0.1 acre (air-dry)
63-65	Total weeds (grassy + broadleaf), listed as lb/0.1 acre
66	2,4=D spray application, listed as 0 = none, 1 = once, 2 = twice, and 3 = 3 times
67	Number of times corn harrowed after planting
68	Number of times corn rotary hoed after planting
69	Number of times corn cultivated
70	Field plowed on the contour, listed as 0 = not contour plowed and 1 = contour plowed
71	Field planted on the contour, listed as 0 = not contour planted and 1 = contour planted
72	Distance in feet to top of terrace ridge above site, coded as 200 - distance in feet (200 feet or a greater distance = 0 and no terrace in the field = 0)
75-76	Number of years to date that field was contour plowed (not contour plowed = 0)
77-78	Number of years to date that field was contour planted (not contour planted = 0)
79-80	Number of years to date since terrace was built within 200 feet above the site (no terrace in the field or 200' or greater distance = 0)

Table A2. Data listing for management variables on original computer card 2

Column	Identification or variable
1	Card no. = 2
2-3	County code no.
4-5	Year (last 2 digits)
6-7	Site no.
8	Seedbed preparation: fall moldboard & others = 0 spring moldboard = 1
9	Seedbed preparation: moldboard (fall or spring) = 0 all others = 1
10	No. tillage operations before plowing: single disked + others
11	No. tillage operations after plowing: single disked + spring-toothed + harrowed + others
12-13	Date planted: in April = April date - 20 in May = May date + 10 in June = June date + 41
14-15	Date 75% silked: in July = July date in August = August date + 31
16	Planting method: drilled = 0 hill dropped and wire-checked = 1
17-18	Hill spacing: drilled = 0 hill dropped: hill spacing to nearest inch
19-20	Row width: average row width to nearest inch - 28"
21-22	Total limestone (tons/10 acres) applied in current year plus 3 previous years
23-24	Manure rate in tons/acre
25-33	Nutrients applied in manure assuming 1 ton = 5#N, 5#P_2O_5 and 10#K_2O (3 col. each)
34-39	Nutrients applied in row fertilizer: lb/acre N, P_2O_5 and K_2O (2 columns each)

Table A2. (Continued)

Column	Identification or variable
40-42	Pounds/acre fertilizer N applied in fall; none or spring-applied or side-dressed N = 0
43-45	Pounds/acre fertilizer N applied in spring (pre-plant); none or fall-applied or side-dressed N = 0
46-48	Pounds/acre fertilizer N side dressed; none or fall- or spring-applied pre-plant N = 0
49-50	Date side dressed: none side dressed = 0 in May = May date in June = June date + 31 in July = July date + 61
51-53	Pounds/acre P_2O_5 plowed under; none or disked-in P = 0
54-56	Pounds/acre P_2O_5 broadcast after plowing and disked in; none or plowed-under P = 0
57-59	Pounds/acre K_2O plowed under; none or disked-in K = 0
60-62	Pounds/acre K_2O broadcast after plowing and disked in; none or plowed-under K = 0
63-71	Total nutrients (N, P_2O_5, and K_2O) applied from manure and all fertilizer applications; sum over columns 25-33, 34-39, 40-48, and 51-62
72-74	Distance to tile listed as: 200 feet - distance to tile; tile ≥ 200 feet from site = 0
75-76	Cropping code for N availability (corn in current year underlined):

$\underline{\text{C}}$-M-M = 08	$\underline{\text{C}}$-Sb-M-M = 08
$\underline{\text{C}}$-M = 10	$\underline{\text{C}}$-Sb-M = 10
$\underline{\text{C}}$-O_M = 15	$\underline{\text{C}}$-Sb-O_M = 14
$\underline{\text{C}}$-C-M-M = 17	$\underline{\text{C}}$-Sb-C-M-M = 15
$\underline{\text{C}}$-C-M = 20	$\underline{\text{C}}$-Sb-C-M = 17
$\underline{\text{C}}$-C-O_M = 25	$\underline{\text{C}}$-Sb-C-O_M = 20
$\underline{\text{C}}$-C-C-M = 30	$\underline{\text{C}}$-Sb-C-C-M = 25
$\underline{\text{C}}$-C-C-O_M = 35	$\underline{\text{C}}$-Sb-C-C-O_M = 30
$\underline{\text{C}}$-C-C-C (cont. corn) = 40	$\underline{\text{C}}$-Sb-C-C-C = 35
$\underline{\text{C}}$-Grass-Grass = 30	

Table A2. (Continued)

Column	Identification or variable	
	Abbreviations: C = corn, M = legume-grass meadow, O_M = oats and legume seeding, and Sb = soybeans.	
77-78	Cropping code for K availability	
	Corn after 3 or more years of corn or after Diverted Acres	00
	Corn after 2 years of corn	05
	Corn after corn, oats or oats and green manure	10
	Corn after soybeans	20
	Corn after soybeans (2 or more years)	30
	Corn after 1 year of meadow (pastured)	30
	Corn after 1 year of meadow (hay and pasture)	35
	Corn after 1 year of meadow (hay) or corn silage	40
	Corn after 2 or more years of meadow (pastured last 2 years)	40
	Corn after 2 or more years of meadow (hay and pasture last 2 years)	50
	Corn after 2 or more years of meadow (hay) or corn silage	60
79	First-brood corn borer control: 0 = none and 1 = insecticide used	
80	Second-brood corn borer control: 0 = none and 1 = insecticide used	

Table A3. Data listing for management and soil test variables on original computer card 3

Column	Identification or variable
1	Card no. = 3
2-3	County code
4-5	Year--last two digits
6-7	Site no.
	Total nutrients applied previous year from fertilizer and manure (1 ton manure = 5 lb N, 5 lb P_2O_5, and 10 lb K_2O)
8-10	Pounds/acre N
11-13	Pounds/acre P_2O_5
14-16	Pounds/acre K_2O
	Total nutrients applied 2 years previously from fertilizer and manure
17-19	Pounds/acre N
20-22	Pounds/acre P_2O_5
23-25	Pounds/acre K_2O
	Total nutrients applied 3 years previously from fertilizer and manure
26-28	Pounds/acre N
29-31	Pounds/acre P_2O_5
32-34	Pounds/acre K_2O
35-36	% slope of site area
37-38	% slope of corn rows through harvest area
39-40	Ratio: $\frac{\text{\% slope of rows}}{\text{\% slope of site}} * 100$ Rows fully on contour = 00 ratio Rows up and down hill = 99 ratio (Set 100 = 99)
41	Aspect (direction of slope) of site--coded 1 to 9, as follows: 1 = SSW 2 = S or SW 3 = SSE or WSW 4 = SE or W 5 = ESE or WNW 6 = E or NW 7 = ENE or NNW 8 = NE or N 9 = NNE

Table A3. (Continued)

Column	Identification or variable
42	Row direction--coded 1 to 9, as follows:
	1 = E-W; 3 = ESE-WNW or ENE-WSW; 5 = NE-SW or SE-NW; 7 = SSE-NNW or NNE-SSW; 9 = N-S
	Soil tests of plow layer from sample taken at harvest
43-44	pH listed as actual pH * 10
45-46	Buffer pH listed as (actual buffer pH - 6.00) * 100; buffer pH $\geq$ 7.00 listed as 99
47-49	N (moist): pp2m nitrifiable N in field-moist sample
53-55	P: pp2m of P; prior to 1963, adjusted to scale of values obtained with present ISU Soil Testing Lab. procedure
56-58	K: pp2m of K in field-moist sample (values > 999 listed as 999)

Table A4. Identification and listing of transformed and transferred data from original management cards 1 to 3 and weather index cards 53 to new cards 1 and 2

Variable symbol	Identification and instructions[a]	Original card No.	Col. no.	X_i	New card No.	Col. No.	X_i
-	New card no. = 1; transfer to Col. 1	1	5	-	1	1	-
-	County code, transfer		6-7	-		2-3	-
-	Year, last 2 digits, transfer		8-9	-		4-5	-
-	Site no., transfer		10-11	-		6-7	-
YIELD	Corn yield, transform to q/ha--X1*0.628		12-14	X1		8-10	X1N
TREND	Time trend, coded 1-14, transfer		15-16	X2		11-12	X2
TIME	Time period; if X2 = 01 to 07, set = 1; if X2 = 08 to 14, set = 2		15-16	X2		13	X2N
PLDEN	Plant density, transform to plants/0.01 ha--X3*2.471		25-27	X3		14-16	X3N
BARR	Barren stalks (%), transfer		28-29	X4		17-18	X4
RL2	Severely root lodged (%), transfer		34-35	X5		19-20	X5
RL3	Total root lodged (%), transfer		36-37	X6		21-22	X6
CRW	Corn root damage rating, transfer		38-39	X7		23-24	X7

[a]If variable is transformed, the 2- or 3-digit whole number transferred to new card is always rounded to nearest whole number.

Table A4. (Continued)

Variable symbol	Identification and instructions	Original card No.	Original card Col. no.	Original card X_i	New card No.	New card Col. no.	New card X_i
INSEFF	Insecticide effectiveness, transfer	1	40	X8	1	25	X8
SL1	Stalks broken below ear (%), transfer		43-44	X9		26-27	X9
CB1	First-brood corn borer, no. cavities per 10 stalks, transfer		47-48	X10		28-29	X10
CB2	Second-brood corn borer, no. of cavities in stalks and shanks, transfer		53-54	X11		30-31	X11
LEAFFEED	Stalks with 1st-brood leaf feeding (%), transfer		55-56	X12		32-33	X12
WEEDS	Total weeds, grassy + broadleaf, transform to kg/0.1 ha--X13*1.121		63-65	X13		34-36	X13N
CULT	No. times hoed and cultivated, transform--X14 + X15		68 69	X14 X15		37	X14N
PLOW	Plowing, coded as fall = 0, spring = 1, none = 2; if Col. 8 and 9 = 0, set = 0; if Col. 8 = 1 and 9 = 0, set = 1; if Col. 9 = 1, set = 2	2	8 9	X16 X17		38	X16N
TILLAFT	Number of tillage operations after plowing, transfer		11	X18		39	X18
PLDATE	Planting date, coded (Table A2), transfer		12-13	X19		40-41	X19

Table A4. (Continued)

Variable symbol	Identification and instructions	Original card No.	Original card Col. no.	Original card X_i	New card No.	New card Col. no.	New card X_i
SLKDATE	75% silking date, coded (Table A2), transfer	2	14-15	X20	1	42-43	X20
PLMETH	Planting method, coded (Table A2), transfer		16	X21		44	X21
ROWWID	Row width, coded width (in.)-28 in., transform to cm--X22*2.54		19-20	X22		45-46	X22N
LIME	Total limestone, T/10A, transform to MT/10 ha--X23*2.24		21-22	X23		47-49	X23N
MANURE	Manure rate, T/A, transform to MT/ha--X24*2.24		23-24	X24		50-51	X24N
ROWFERT	Row fertilizer applied; coded as 0 = none and some = 1; if X26 = 0, set = 0, if X26 > 0, set = 1		36-37	X26		52	X26N
NROW	N fertilizer applied in row, transform to kg N/ha--X25*1.12		34-35	X25		53-54	X25N
PROW	P fert. applied in row, transform to kg P/ha--X26*0.49		36-37	X26		55-56	X26N
KROW	K fert. applied in row, transform to kg K/ha--X27*0.93		38-39	X27		57-58	X27N

Table A4. (Continued)

Variable symbol	Identification and instructions	Original card No.	Original card Col. no.	Original card X_i	New card No.	New card Col. no.	New card X_i
NBDCT	N fertilizer applied in fall, spring, and side-dressed; add and transform to kg N/ha--(X28 + X29 + X30)*1.12; if > 336 kg/ha, set = 336	2	40-42 43-45 46-48	X28 X29 X30	1	59-61	X28N
NTIME	Time of N application; coded as 00 = none, 10 = fall, 20 = spring preplant, 30 = sidedressed; transform-- $\frac{(X28*10)+(X29*20)+(X30*30)}{X28 + X29 + X30}$		40-42 43-45 46-48	X28 X29 X30		62-63	X29N
NSD	N fertilizer side-dressed, transform to kg N/ha--X30*1.12		46-48	X30		64-66	X30N
SDDATE	Date side-dressed, coded (Table A2), transfer		49-50	X31		67-68	X31
PBDCT	P fertilizer BPU and BDI; add and transform to kg P/ha--(X32 + X33)*0.49; if > 98 kg/ha, set = 98		51-53 54-56	X32 X33		69-70	X32N
PMETH	Method of P application; coded 00 = none, 10 = BPU, 20 = BDI; transform-- $\frac{(X32*10) + (X33*20)}{X32 + X33}$		51-53 54-56	X32 X33		71-72	X33N
KBDCT	K fertilizer BPU and BDI; add and transform to kg K/ha--(X34 + X35)*0.93; if > 223 kg K, set = 223		57-59 60-62	X34 X35		73-75	X34N

Table A4. (Continued)

Variable symbol	Identification and instructions	Original card No.	Original card Col. no.	Original card X_i	New card No.	New card Col. no.	New card X_i
KMETH	Method of K application; coded 00 = none, 10 = BPU, 20 = BDI; transform-- $\frac{(X34*10) + (X35*20)}{X34 + X35}$	2	57-59 60-62	X34 X35	1	76-77	X35N
TILE	Distance to tile, coded as (200'-distance), transform to meters--X36*0.305		72-74	X36		78-80	X36N
-	New card = 2, transfer	2	1	-	2	1	-
-	County code, transfer		2-3	-		2-3	-
-	Year, last 2 digits, transfer		4-5	-		4-5	-
-	Site no., transfer		6-7	-		6-7	-
NTOTAL	Total N from manure and all fertilizer; transform to kg N/ha--X38*1.12; if > 336 kg/ha, set = 336		63-65	X38		8-10	X38N
PTOTAL	Total P from manure and all fert.; transform to kg P/ha--X38*0.49; if > 98 kg/ha, set = 98		66-68	X39		11-12	X39N
KTOTAL	Total K from manure and all fert.; transform to kg K/ha--X40*0.93; if > 223 kg/ha, set = 223		69-71	X40		13-15	X40N
NFERT	Total N from fert.; subtract and transform to kg N/ha--(X38-X41)*1.12; if > 336, set = 336		25-27 63-65	X41 X38		16-18	X41N
PFERT	Total P from fert.; subtract and transform to kg P/ha--(X39-X42)*0.49; if > 98, set = 98		28-30 66-68	X42 X39		19-20	X42N

Table A4. (Continued)

Variable symbol	Identification and instructions	Original card No.	Original card Col. no.	Original card X_i	New card No.	New card Col. no.	New card X_i
KFERT	Total K from fert.; subtract and transform to kg K/ha--(X40-X43)*0.93; if > 223, set = 223	2	31-33 69-71	X43 X40	2	21-23	X43N
NCODE	Cropping code for N availability (Table A2), transfer		75-76	X44		24-25	X44
KCODE	Cropping code for K availability, (Table A2), transfer		77-78	X45		26-27	X45
NRES1	Total N applied previous year; transform to kg N/ha--X46*1.12; if > 336, set = 336	3	8-10	X46		28-30	X46N
PRES1	Total P applied previous year; transform to kg P/ha--X47*0.49; if > 98, set = 98		11-13	X47		33-35	X47N
KRES1	Total K applied previous year; transform to kg K/ha--X48*0.93; if > 223, set = 223		14-16	X48		33-35	X48N
NRES2	Total N applied 2 years previously; transform to kg N/ha--X49*1.12; if > 336, set = 336		17-19	X49		36-38	X49N
PRES2	Total P applied 2 years previously; transform to kg P/ha--X50*0.49; if > 98, set = 98		20-22	X50		39-40	X50N
KRES2	Total K applied 2 years previously; transform to kg K/ha--X51*0.93; if > 223, set = 223		23-25	X51		41-43	X51N

Table A4. (Continued)

Variable symbol	Identification and instructions	Original card No.	Original card Col. no.	Original card X_i	New card No.	New card Col. no.	New card X_i
PRES3	Total P applied 3 years previously; transform to kg P/ha--X52*0.49; if > 98, set = 98	3	29-31	X52	2	44-45	X52N
KRES3	Total K applied 3 years previously; transform to kg K/ha--X53*0.93; if > 223, set = 223		32-34	X53		46-48	X53N
SLOPE	Percent slope of site area, transfer		35-36	X54		49-50	X54
ROWSLOPE	Percent slope of rows through harvest area, transfer		37-38	X55		51-52	X55
SLRATIO	Ratio of (% slope of rows/% slope of site)* 100, transfer		39-40	X56		53-54	X56
ROWDIR	Row direction, coded (Table A3), transfer		42	X57		55	X57
PH1	pH of plow layer; coded (Table A3); transform --X58-50		43-44	X58		56-57	X58N
PHB	Buffer pH of plow layer, coded (Table A3), transfer		45-46	X59		58-59	X59
STN	Soil test N (moist) of plow layer in pp2m, if > 100, set = 100, transfer		47-49	X60		60-62	X60N
STP1	Soil test P of plow layer in pp2m, if > 100, transfer		53-55	X61		63-65	X61N

Table A4. (Continued)

Variable symbol	Identification and instructions	Original card No.	Original card Col. no.	Original card X_i	New card No.	New card Col. no.	New card X_i
STK1	Soil test K (moist) of plow layer in pp2m, if > 400, set = 400, transfer	3	56-58	X62	2	66-68	X62N
DV	Moisture stress index	53	10-14	X63		69-73	X63
EXMO	Excess moisture index		17-21	X64		74-78	X64

Table A5. Data listing for soil variables on computer card 05 (revised 2-14-80)

Columns	Identification or variable
1-2	Card no. = 05
3-4	County code (Adams = 02 to Woodbury = 97)
5-6	Site no.
7-10	Soil unit no. (col. 7 indicates variant; 1010 and 2010 are Monona variants)
11-12	Location--Township no. (T67 to T99; T100 = T99)
13-14	Location--Range no. (R1E = 0, R1W = 1 to R48W = 48)
15	Slope configuration, where: 1 = strongly convex; 4 = straight (flat) 2 = convex; 5 = straight to concave 3 = convex to straight; 6 = concave
16	Erosion class, where: 0 = + (deposition) or none (> 12" A horizon) 1 = slight (7-12" A horizon) 2 = moderate (3-7" A horizon) 3 = severe (< 3" A horizon)
17-18	Thickness of A horizon ($A_1 + A_2 + A_3$) in inches
19-20	Est. % organic carbon of 0-7" layer (coded: %OC * 10)
21-22	Est. % OC of 7-20" layers (coded: wtd. av. %OC * 10)
23-24	Color value of 0-7" layer (coded: value * 10)
25-26	Color chroma of 0-7" layer (coded: chroma * 10)
27-28	Color value of 7-20" layers (coded: wtd. av. * 10)
29-30	Color chroma of 7-20" layers (coded: wtd. av. * 10)
31-32	Natural internal drainage class, where:

Table A5. (Continued)

Columns	Identification or variable
	10 = excessive; 20 = excessive to well; 30 = well; 40 = moderately well; 50 = somewhat poor; 60 = somewhat poor to poor; 70 = poor; 80 = poor to very poor; 90 = very poor
33-34	Subsoil permeability class, where:
	00 = very rapid; 10 = rapid; 20 = rapid to mod. rapid; 30 = moderately rapid; 40 = mod. rapid to moderate; 50 = moderate; 60 = moderate to slow; 70 = slow; 80 = slow to very slow; 90 = very slow
35-36	% clay in plow-layer
37-38	Maximum % clay in subsoil (below plow-layer)
39-40	Average % clay in 0-60" profile
41-42	Depth to mid-point of horizon(s) with maximum % clay
43	Subsoil group rating for crop growth, where:
	0 = very favorable; 1 = favorable; 2 = slightly unfavorable; 3 = slightly to mod. unfavorable; 4 = moderately unfavorable; 5 = mod. to very unfavorable; 6 = very unfavorable
44	Biosequence, where
	1 = forest; 2 = forest-transition intergrade; 3 = transition; 4 = transition-prairie intergrade; 5 = prairie
45-46	Location on landscape (dummy variables), where:

	Col. 45	Col. 46
Upland, footslope	0	0
Terrace, outwash	1	0
Bottomland	0	1

Table A5. (Continued)

Columns	Identification or variable
47-48	Bulk density (g/cm^3) at 15-30"; coded (value-1.00)100
49-50	Bulk density (g/cm^3) at 30-40"; coded (value-1.00)100
51	Subsoil structure (B horizon or comparable zone), where:

1 = structureless (massive or single-grain)	4 = weak to moderate
2 = structureless to weak	5 = moderate
3 = weak	6 = mod. to strong
	7 = strong

Columns	Identification or variable
52-57	Parent material grouping (dummy variables--0 or 1 entries)

	Column no.					
	52	53	54	55	56	57
1. Deep loess	0	0	0	0	0	0
2. Loess/till or paleosol (20-50" loess)	1	0	0	0	0	0
3. Till	0	1	0	0	0	0
4. Paleosol	0	0	1	0	0	0
5. Sand (0-50" to sand)	0	0	0	1	0	0
6. Colluvium	0	0	0	0	1	0
7. Alluvium (all except (0-50" to sand)	0	0	0	0	0	1

58-59 Depth to, or thickness of, following characteristics in parent material grouping (coded: 60"-depth; more than 60" = 0)

1. Depth to deoxidized loess in deep loess units
2. Depth to till or paleosol in shallow loess (20-50") units
3. Thickness of silty overburden or reworked materials over till
4. Thickness of overburden or loess over paleosol
5. Depth (0-50") to loamy sand, sand, or gravel
6. Colluvium - none
7. Alluvium - none

60-61	Minimum pH in subsoil (below plow-layer) (coded: pH * 10)
62-63	Depth to midpoint of minimum pH layer in subsoil (inches)
64-65	Thickness of minimum pH zone (inches)

Table A5. (Continued)

Columns	Identification or variable
66-67	Depth to top of calcareous horizon (coded: 60"-depth; more than 60" = 0)
68-69	pH of 10-20" layer (coded: pH * 10)
70-71	pH of 30-42" layer (coded: pH * 10)
72-73	pH of 42-60" layer (coded: pH * 10)
74-75	Soil test P of 10-20" layer (pp2m P)
76-77	Soil test P of 30-42" layer (pp2m P)
78-80	Soil test K of 12-24" layer (pp2m K)

Table A6. Identification and listing of transformed and transferred data from repunched soil variable card 05 to new soil variable card 05

Identification and instructions	Repunched card 05 Col. no.	Repunched card 05 X_i	New card 05 Col. no.	New card 05 X_i
New card no. = 05; punch in col. 1-2	1-2	-	1-2	-
County code, transfer	3-4	-	3-4	-
Site number, transfer	5-6	-	5-6	-
Soil mapping no., transfer	7-10	-	7-10	-
Township no., subtract 65, transfer	11-12	X1	11-12	X1N
Range no., transfer	13-14	X2	13-14	X2
Slope configuration, transfer	15	X3	15	X3
Erosion class, transfer	16	X4	16	X4
Thickness of A horizon, multiply by 2.54, transfer nearest whole number, if > 99 set = 99 cm	17-18	X5	17-18	X5N
% OC in 0-7" layer (*10)	19-20	X6		
% OC in 7-20" layer (*10)	21-22	X7		
Compute wtd. average in 0-20" layer by $\frac{(7*\text{Col. }19\text{-}20)+(13*\text{Col. }21\text{-}22)}{20}$, transfer nearest whole number			19-20	X6N
Drainage class, transfer	31-32	X12	21-22	X12
Permeability class, transfer	33-34	X13	23-24	X13
% clay in plow layer, transfer	35-36	X14	25-26	X14
Max. clay in subsoil, transfer	37-38	X15	27-28	X15
Av. clay in 0-60" profile, transfer	39-40	X16	29-30	X16
Depth to max. clay, multiply by 2.54, transfer nearest whole number	41-42	X17	31-33	X17N

Table A6. (Continued)

Identification and instructions	Repunched card 05 Col. no.	Repunched card 05 X_i	New card 05 Col. no.	New card 05 X_i
Subsoil group rating, transfer	43	X18	34	X18
Biosequence, transfer	44	X19	35	X19
Landscape location-terrace, transfer	45	X20	36	X20
Landscape location-bottomland, transfer	46	X21	37	X21
Bulk density (30-40"), transfer	49-50	X23	38-39	X23
Subsoil structure, transfer	51	X24	40	X24
Parent material coded as follows, transfer				
Deep loess (Col. no. 52–57: 0 0 0 0 0 0)	-	-	-	-
Loess/till, paleo. (1 0 0 0 0 0)	52	X25	41	X25
Till (0 1 0 0 0 0)	53	X26	42	X26
Paleosol (0 0 1 0 0 0)	54	X27	43	X27
Sand (0-50") (0 0 0 1 0 0)	55	X28	44	X28
Colluvium (0 0 0 0 1 0)	56	X29	45	X29
Alluvium (0 0 0 0 0 1)	57	X30	46	X30
Depth to, or thickness of, a subsoil characteristic given in Table A5, multiply X31*2.54, transfer nearest whole number	58-59	X31	47-49	X31N
Compute and transfer nearest whole number for the following transformed variables using Col. 52-57, X25-X28, and X31				
1. Depth to deox. loess: if Col. 52-57 = 0, multiply X31*2.54 transfer			50-52	X31N1
2. Depth to till, paleosol in loess/till units: multiply X25*X31*2.54, transfer			53-55	X31N2
3. Depth to till in till units: multiply X26*X31*2.54, transfer			56-58	X31N3

Parent material coding (Col. no.):

	52	53	54	55	56	57
Deep loess	0	0	0	0	0	0
Loess/till, paleo.	1	0	0	0	0	0
Till	0	1	0	0	0	0
Paleosol	0	0	1	0	0	0
Sand (0-50")	0	0	0	1	0	0
Colluvium	0	0	0	0	1	0
Alluvium	0	0	0	0	0	1

Table A6. (Continued)

Identification and instructions	Repunched card 05		New card 05	
	Col. no.	X_i	Col. no.	X_i
4. Depth to paleosol in paleosol units: multiply X27*X31*2.54, transfer			56-58	X31N3
5. Depth to sand in units with sand < 50" (127 cm) deep: multiply X28*X31*2.54, transfer			62-64	X31N5
Minimum pH in subsoil (coded pH*10), subtract 45 from X32, transfer	60-61	X32	65-66	X32N
Depth to minimum pH, multiply X33*2.54, transfer nearest whole number, if > 99 set = 99 cm	62-63	X33	67-68	X33N
Depth to top of carbonate layer (coded 60"-depth), multiply X35*2.54, transfer nearest whole number	66-67	X35	69-71	X35N
pH of 30-42" (76-107 cm) layer, subtract 45 from X37, transfer	70-71	X37	72-73	X37N
Soil test P of 30-42" (76-107 cm) layer, transfer	76-77	X40	74-75	X40
Soil test K of 12-24" (30-61 cm) layer, transfer	78-80	X41	76-78	X41

Table A7. Analysis of variance, final MODELS A-35, B-30, and J-10

Variation due to	DF	Sum of squares	Mean squares	F ratio	R^2
		MODEL A-35			
Total	2656	835018.631539			
Regression	42	503899.278653	11997.601873	94.7143	0.60346
Residual	2614	331119.352886	126.671520		
		MODEL B-30			
Total	2656	835018.631539			
Regression	58	528905.299311	9119.056885	77.3939	0.63341
Residual	2598	306113.332228	117.826533		
		MODEL J-10			
Total	2656	835018.631539			
Regression	80	568272.758489	7103.409481	68.5986	0.68055
Residual	2576	266745.873050	103.550417		

Table A8. Data listing for plant available water capacity (PAWC) on new computer card 3

Identification and instructions	SMP card 12 (column no.)	New card 3 (column no.)
New card no. = 3	--	1
County code, transfer	7-8	2-3
Year, transfer	5-6	4-5
Site no., transfer	3-4	6-7
Total PAWC (in. H_2O/5 ft), transfer	68-72	8-12

Table A9. Data listing for management variables transferred from new card 1 to new card 4

Variable symbol	Identification	New card 1 (column no.)	New card 4 (column no.)
--	New card no., transfer from 1 to 4	1	4
--	County code	2-3	2-3
--	Year, last 2 digits	4-5	4-5
YIELD	Corn yield, q/ha	8-10	8-10
PLDEN	Plant density, plants/0.01 ha	14-16	11-13
WEEDS	Total grassy and broadleaf weeds, kg/0.1 ha	34-36	14-16
NBDCT	N fertilizer applied in fall, spring, and side dressed, kg N/ha	59-61	17-19
TILE	Distance to tile, coded: 61 m - distance in m	78-80	20-22
RL3	Total root lodged, %	21-22	23-24
CRW	Corn root damage rating	23-24	25-26
SL1	Stalks broken below ear, %	26-27	27-28
CB1	First-brood corn borer, cavities/10 stalks	28-29	29-30
CB2	Second-brood corn borer, cavities/10 stalks	30-31	31-32
PLDATE	Planting date, coded (Table A2)	40-41	33-34

Table A9. (Continued)

Variable symbol	Identification	New card 1 (column no.)	New card 4 (column no.)
MANURE	Manure rate, MT/ha	50-51	35-36
PROW	P fertilizer applied in row, kg P/ha	55-56	37-38
PBDCT	P fertilizer broadcast, kg P/ha	69-70	39-40
CULT	No. of times hoed and cultivated	37	41
TILLAFT	No. of tillage operations after plowing	39	42
PLMETH	Planting method, coded (Table A2)	44	43

APPENDIX B

Table B1. Computer program used to transform and transfer data from original management cards 1, 2, and 3 and climatic indexes card 53 to new cards 1 and 2

```
$JCB              SRIDODO,TIME=30,PAGES=100
C      ****************************************************************
C      *                                                              *
C      *  PROGRAM TO TRANSFORM AND TRANSFER DATA TO NEW DATA DECK --  *
C      *  SRIDODO'S CARDS NO 1 AND 2.                                 *
C      *                                                              *
C      ****************************************************************
       IMPLICIT INTEGER (A-H,O-Z)
       REAL X63, X64
     1 READ (5,11, END=100) CARD1,SITE1,X1,X2,X3,X4,X5,X6,X7,X8,X9,X10,
      1X11,X12,X13,X14,X15,CARD2,SITE2,X16,X17,X18,X19,X20,X21,X22,X23,
      2X24,X41,X42,X43,X25,X26,X27,X28,X29,X30,X31,X32,X33,X34,X35,X38,
      3X39,X40,X36,X44,X45,CARD3,SITE3,X46,X47,X48,X49,X50,X51,X52,X53,
      4X54,X55,X56,X57,CARD3A,SITE3A,X58,X59,X60,X61,X62,CARD53,SITE53,
      5X63,X64
    11 FORMAT (4X,I1,I6,I3,I2,8X,I3,I2,4X,3I2,I1,2X,I2,2X,I2,4X,2I2,6X,
      1I3,2X,2I1/I1,I6,2I1,1X,I1,2I2,I1,2X,3I2,3I3,3I2,3I3,I2,8I3,2I2/I1,
      2I6,6I3,3X,2I3,3I2,1X,I1/I1,I6,35X,2I2,I3,3X,2I3/I2,I6,1X,F5.2,2X,
      3F5.2)
       IF (SITE1.NE.SITE2.OR.SITE2.NE.SITE3.OR.SITE3.NE.SITE3A.OR.SITE3A.
      1NE.SITE53) GO TO 99
       IF (CARD1.NE.1.OR.CARD2.NE.2.OR.CARD3.NE.3.OR.CARD3A.NE.3.OR.
      1CARD53.NE.53) GO TO 99
       IF(CARD3.EQ.3.AND.X57.EQ.0) GO TO 99
       X1= X1 * .628 + .5
       IF (X2.GT.7) GO TO 12
       X2N=1
       GO TO 21
    12 X2N=2
    21 X3=X3 * 2.471 + .5
       X13=X13 * 1.121 + .5
       CULT=X14 + X15
       PLOW=X16 + X17
       IF (PLOW.GE.1) GO TO 22
       PLOW=0
```

Table B1. (Continued)

```
      GO TO 31
   22 IF(X17.EQ.1) GO TO 23
      PLOW=1
      GO TO 31
   23 PLOW=2
      CONTINUE
   31 X22=X22 * 2.54 + .5
      X23=X23 * 2.24 + .5
      X24=X24 * 2.24 + .5
      IF(X26.GT.0) GO TO 32
      X26N=0
      GO TO 41
   32 X26N=1
   41 X25=X25 * 1.12 + .5
      X26=X26 * .49 + .5
      X27=X27 * .93 + .5
      NBDCT=(X28+X29+X30)*1.12 + .5
      IF(NBDCT.GT.336) NBDCT=336
      SUM=X28+X29+X30
      IF(SUM.EQ.0) GO TO 42
      NTIME=((X28*10.0 + X29*20.0 + X30*30.0)/(X28+X29+X30)) + .5
      GO TO 45
   42 NTIME=0
      GO TO 45
   45 X30=X30*1.12 + .5
      PBDCT=(X32+X33)* .49 + .5
      IF (PBDCT.GT.98) PBDCT=98
      SUM1=X32+X33
      IF(SUM1.EQ.0) GO TO 47
      PMETH=((X32*10.0 + X33*20.0)/(X32+X33)) + .5
      GO TO 48
   47 PMETH=0
      GO TO 48
   48 KBDCT=(X34+X35)* .93 + .5
      IF (KBDCT.GT.223)  KBDCT=223
```

Table B1. (Continued)

```
      SUM2=X34+X35
      IF(SUM2.EQ.0) GO TO 60
      KMETH= ((X34*10.0 + X35*20.0)/(X34+X35)) + .5
      GO TO 61
   60 KMETH=0
      GO TO 61
   61 X36=X36* .305 + .5
      X38N=X38*1.12 + .5
      IF (X38N.GT.336)  X38N=336
      X39N=X39* .49 + .5
      IF (X39N.GT.98)  X39N=98
      X40N=X40* .93 + .5
      IF (X40N.GT.223)  X40N=223
      NFERT=(X38 - X41)*1.12 + .5
      IF (NFERT.GT.336)  NFERT=336
      PFERT=(X39 - X42) * .49 + .5
      IF (PFERT.GT.98)  PFERT=98
      KFERT=(X40 - X43) * .93 + .5
      IF (KFERT.GT.223)  KFERT=223
      X46=X46*1.12 + .5
      IF(X46.GT.336)  X46=336
      X47=X47* .49 + .5
      IF(X47.GT.98)  X47=98
      X48=X48* .93 + .5
      IF(X48.GT.223)  X48=223
      X49=X49*1.12 + .5
      IF(X49.GT.336)  X49=336
      X50=X50* .49 + .5
      IF(X50.GT.98)  X50=98
      X51=X51* .93 + .5
      IF(X51.GT.223)  X51=223
      X52=X52* .49 + .5
      IF(X52.GT.98)  X52=98
      X53=X53* .93 + .5
      IF(X53.GT.223)  X53=223
```

Table B1. (Continued)

```
      X58 = X58-50
      IF(X60.GT.100)  X60=100
      IF(X61.GT.100)  X61=100
      IF(X62.GT.400)  X62=400
      WRITE (7,80) CARD1,SITE1,X1,X2,X2N,X3,X4,X5,X6,X7,X8,X9,X10,X11,
     1X12,X13,CULT,PLOW,X18,X19,X20,X21,X22,X23,X24,X26N,X25,X26,X27,
     2NBDCT,NTIME,X30,X31,PBDCT,PMETH,KBDCT,KMETH,X36
   80 FORMAT     (I1,I6,I3,I2,I1,I3,4I2,I1,4I2,I3,3I1,2I2,I1,I2,I3,I2,
     1I1,3I2,I3,I2,I3,3I2,I3,I2,I3)
      WRITE (7,81) CARD2,SITE2,X38N,X39N,X40N,NFERT,PFERT,KFERT,X44,X45,
     1X46,X47,X48,X49,X50,X51,X52,X53,X54,X55,X56,X57,X58,X59,X60,X61,
     2X62,X63,X64
   81 FORMAT     (I1,I6,I3,I2,2I3,I2,I3,2I2,I3,I2,2I3,I2,I3,I2,I3,3I2,
     1I1,2I2,3I3,2F5.2)
      GO TO 1
   99 WRITE (6,991) CARD1,SITE1,CARD2,SITE2
  991 FORMAT ('CCARDS ARE NOT IN ORDER' , 2X,I1,1X,I6,2X,I1,1X,I6)
  100 CONTINUE
      STOP
      END
$ENTRY                                                               00000006
```

Table B2. Computer program used to transfer and transform soil variable data from repunched card 05 to new soil variable data card 05

```
$JOB            SRIDODO,TIME=5,PAGES=10
C      ***********************************************************
C      *                                                         *
C      * PROGRAM TO TRANSFER AND TRANSFORM SOIL PARAMETER        *
C      * FROM ORIGINAL REPUNCHED CARD #05 TO NEW CARD # 05       *
C      *                                                         *
C      ***********************************************************
       IMPLICIT INTEGER (A-H,O-Z)
       CHARACTER*2 CARD,COUNTY,SITE
       CHARACTER*4 SMAPP
     1 READ (5,11, END=100) CARD,COUNTY,SITE,SMAPP,X1,X2,X3,X4,X5,X6,X7,X
      112,X13,X14,X15,X16,X17,X18,X19,X20,X21,X23,X24,X25,X26,X27,X28,X29
      2,X30,X31,X32,X33,X35,X37,X40,X41
    11 FORMAT (3A2,A4,2I2,2I1,3I2,8X,6I2,4I1,2X,I2,7I1,3I2,2X,I2,2X,I2,
      14X,I2,I3)
       X1N=X1 - 65
       X5N= X5 * 2.54 + .5
       X6N=(7*X6) + (13*X7)
       X6NN=(X6N/20.0) +0.5
       X17N=X17*2.54 +.5
       X31N=X31*2.54 +.5
       XDUM=X25+X26+X27+X28+X29+X30
       IF (XDUM.NE.0) GO TO 33
       X31N1=X31*2.54 +.5
       X31N2=0
       X31N3=0
       X31N4=0
       X31N5=0
       GO TO 44
    33 X31N1=0
       X31N2=X25*X31*2.54 +.5
       X31N3=X26*X31*2.54 +.5
       X31N4=X27*X31*2.54 +.5
       X31N5=X28*X31*2.54 +.5
    44 X32N=X32-45
```

Table B2. (continued)

```
      X33N=X33*2.54 +.5
      X35N=X35*2.54 +.5
      X37N=X37-45
      WRITE (7,23) CARD,COUNTY,SITE,SMAPP,X1N,X2,X3,X4,X5N,X6NN,X12,X13,
     1X14,X15,X16,X17N,X18,X19,X20,X21,X23,X24,X25,X26,X27,X28,X29,X30,X
     231N,X31N1,X31N2,X31N3,X31N4,X31N5,X32N,X33N,X35N,X37N,X40,X41
   23 FORMAT    (3A2,A4,2I2,2I1,7I2,I3,4I1,I2,7I1,6I3,2I2,I3,2I2,I3)
      GO TO 1
  100 CONTINUE
      STOP
      END
$ENTRY                                                          00000006
```

Table B3. Computer program used to produce soil variable data card 51 from new soil variable data card 05

```
$JOB            SRIDODO,TIME=10,PAGES=10
C      *****************************************************
C      *                                                   *
C      *    PROGRAM TO REPRODUCE CARD #51 SOIL  PARAME-    *
C      *    TER FROM EACH CO., LOC. TO EACH CO., YEAR,     *
C      *    AND LOC.  CARD 51                              *
C      *                                                   *
C      *****************************************************
       IMPLICIT INTEGER (A-H,O-Z)
       CHARACTER*2 NCTY,NSTE,NCTYP,NSTEP
       CHARACTER*4 SMAPP
       DIMENSION IYR (14)
    10 READ(5,11,END=100) NCTY,NSTE,SMAPP,X1,X2,X3,X4,X5,X6,X7,X8,X9,X10,
      1X11,X12,X13,X14,X15,X16,X17,X18,X19,X20,X21,X22,X23,X24,X25,X26,
      2X27,X28,X29,X30,X31,X32,X33,X34,X35,X36,NCTYP,NSTEP,NYR,IYR
    11 FORMAT (2X,2A2,A4,2I2,2I1,7I2,I3,4I1,I2,7I1,6I3,2I2,I3,2I2,I3/1X,
      12A2,15I2)
       IF(NCTY.NE.NCTYP.OR.NSTE.NE.NSTEP) GO TO 300
       DO 22 I=1,NYR
    20 WRITE(7,21) NCTY,IYR(I),NSTE,SMAPP,X1,X2,X3,X4,X5,X6,X7,X8,X9,X10,
      1X11,X12,X13,X14,X15,X16,X17,X18,X19,X20,X21,X22,X23,X24,X25,X26,
      2X27,X28,X29,X30,X31,X32,X33,X34,X35,X36
    22 CONTINUE
    21 FORMAT('51',A2,I2,A2,A4,2I2,2I1,7I2,I3,4I1,I2,7I1,6I3,2I2,I3,2I2,
      1I3)
       GO TO 10
   100 WRITE (6,101)
   101 FORMAT ('0', 'END OF DATA')
       STOP
   300 WRITE(5,301) NCTY,NCTYP,NSTE,NSTEP
   301 FORMAT('0','****ERROR; COUNTIES ARE :',2I5,'; SITES ARE : ',2I5)
       STOP
       END
 $ENTRY                                                          00000006
```

Table B4. Computer program used to transfer plant available water capacity (PAWC) data from soil moisture program data card 12 to new data card 3

```
$JOB            SRIDODO,TIME=10,PAGES=10
C      *********************************************************
C      *                                                       *
C      *   PROGRAM TO TRANSFER PAWC FROM SMP CARD # 12 TO      *
C      *    NEW CARD # 3 .                          SRIDODO    *
C      *                                                       *
C      *********************************************************
      REAL PAWC
      INTEGER NCARD,NST1,NST2,YEAR,NCTY
   10 READ (5,11, END=100) NCARD,NST1,NST2,YEAR,NCTY,PAWC
   11 FORMAT (I2,2I1,2I2,59X,F5.2)
      IF (NCARD.NE.12) GO TO 40
      WRITE (7,21) NCTY,YEAR,NST1,NST2,PAWC
   21 FORMAT ('3',I2,I2,2I1,F5.2)
      GO TO 10
  100 WRITE (6,101)
  101 FORMAT ('0', 'SUCCESSFUL RUN')
      STOP
   40 WRITE (6,301) NST1,NST2,YEAR,NCTY
  301 FORMAT ('0','***WRONG CARD; SITE IS :',2I1,2I2)
      STOP
      END
$ENTRY                                                    00000006
```

Table B5. Computer program used to transfer some of the management variables from new data card 1 to new data card 4

```
$JOB              SRIDODO,TIME=10,PAGES=100
C       ****************************************************************
C       *                                                              *
C       *  SRIDODOHS PROGRAM TO TRANSFER MANAGEMENT VAR. TO BE         *
C       *  INCLUDED IN THE QUADRATIC REG. FOR SOIL, MANAGMT. AND       *
C       *  CLIMATIC VAR.  FROM CARD # 1 TO CARD # 4 .                  *
C       *                                                              *
C       ****************************************************************
        IMPLICIT INTEGER (A-H,O-Z)
        CHARACTER*6 SITE
      1 READ (5,10, END=100) CARD,SITE,X1,X2,X3,X4,X5,X6,X7,X8,X9,X10,X11,
       1X12,X13,X14,X15,X16,X17
     10 FORMAT (I1,A6,I3,3X,I3,4X,2I2,1X,3I2,2X,I3,I1,1X, I1,I2,2X,I1,5X,
       2I2,3X,I2,2X,I3,7X,I2,7X,I3)
        IF (CARD.NE.1) GO TO 50
        WRITE (7,20) SITE,X1,X2,X8,X15,X17,X3,X4,X5,X6,X7,X11,X13,X14,
       1X16,X9,X10,X12
     20 FORMAT ('4',A6,5I3,9I2,3I1)
        GO TO 1
    100 WRITE (6,101)
    101 FORMAT ('0','COMPLETE RUN')
        STOP
     50 WRITE (6,51) CARD, SITE
     51 FORMAT ('0','***WRONGCARD; SITE ARE :',I1,A6)
        STOP
        END
$ENTRY                                                          00000005
```